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Status of Biomass Feeder Technology

by

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NOMENCLATURE AND DEFINITIONS

A. DEFINITIONS

$$\text{Moisture Content, Wet Basis} = \frac{\text{(weight wet sample-weight dry sample)}}{\text{weight wet sample}} \times 100\%$$

$$\text{Moisture Content, Dry Basis} = \frac{\text{(weight wet sample-weight dry sample)}}{\text{weight dry sample}} \times 100\%$$

Unit - 200 cubic feet of loose wood residue

Prefixes for Metric Units:
$m = 10^{-3}$
$c = 10^{-2}$
$k = 10^{3}$
$M = 10^{6}$
$G = 10^{9}$

B. NOMENCLATURE

BD	bone dry, zero percent moisture content
db	dry basis moisture content
ft^3SWE	cubic feet of solid wood equivalent
g	gram (1 kg = 2.205 pounds)
h	hour
J	Joule (1 kJ = 0.9479 BTU)
l	litre (1 l = 0.22 Imperial Gallon)
m	meter (1 m = 3.2808 feet)
%mc	moisture content percent
min	minute
Pa	pascal (1 Pa = 0.145 psi)
rpm	revolutions per minute
s	second
t	tonne (1 t - 1.1025 ton)

v/v	volume basis
W	Watt (1 kW = 1.3405 horsepower)
wb	wet basis moisture content
wt%	percent on a weight basis

I. SUMMARY

A comprehensive survey of feeders was conducted to compile performance characteristics and costs of commercial equipment for handling wood residues and to identify newly developed feeders that may be appropriate for wood residues. The discussion for each feeder covers design and operating principles, performance characteristics and costs, guidelines for proper use, applications, status of technology and use, and manufacturers. Primary emphasis was placed on feeders capable of moving solids across a differential pressure such as would exist when feeding a pressurized combustor or gasifier.

During the survey of manufacturers to identify available equipment, the only limitation on scope was that the feeder should have some potential, possibly unproven, for feeding wood residues. The suitability of the feeder for wood residues was determined by the manufacturer.

Several commercial and newly developed feeders were identified that have potential for feeding wood residues against a backpressure. At differential pressures up to 1,000 kPa, several well-proven feeders are available for feeding pulp chips. These could be adapted to feeding forest biomass fuels, although tests are needed to determine the suitability of these feeders for hogged residues containing particles larger than pulp chips, or stringy residues, or bark.

For feeding wood residues across differential pressures in excess of 1,000 kPa, the prime candidates are:

Linear Pocket Feeders
Lock Hopper Feeders
Lurgi Schlepper piston feeder
Ingersoll-Rand Co-axial piston feeder
Rotary Feeders
Werner Pfleiderer Co-rotating screw feeder
Koppers plug screw feeder
General Electric screw feeder
C.E. Bauer Pressafiner (screw feeder)
Stake Technology Co-axial screw feeder
Ingersoll-Rand reciprocating screw feeder

Potential high-pressure feeders and their compatibility with three size groupings of wood residues are summarized in Table I-1. A new feeder of particular interest for feeding wood residues is the reciprocating screw feeder developed by Ingersoll-Rand. This unit has not operated with wood residues. Such a test is recommended.

TABLE I-1

Potential High-Pressure Feeders for Wood Residues

FEEDER	OPERATED WITH WOOD RESIDUES?	SUGGESTED PARTICLE SIZES* FOR WOOD FEED		
		<1 cm	1 - 5 cm	>5 cm
C.E. Bauer Pressafiner	Yes	P	P	T
General Electric Srew Feeder	No	T	T	T
Ingersoll-Rand Piston Feeder	No	T	T	
Ingersoll-Rand Screw Feeder	No	T	T	T
Koppers Screw Feeder	Yes	P	P	T
Linear Pocket Feeder	No	T	T	
Lock Hopper Feeders	Yes	P	P	P
Lurgi Piston Feeders	Yes	T	T	
Rotary Feeders	Yes	P		
Stake Technology Screw Feeder	Yes	P	P	T
Werner Pfleiderer Screw Feeder	Yes	D	T	

*Based on general characteristics of the feeder design and data obtained in this study.

Key:
P - Proven
D - Demonstrated
T - Needs Testing

II. INTRODUCTION

A. Background

Energy conversion systems for forest biomass are diverse in operating principle, size, feed materials and configuration. This has led to an equal diversity in the design and capability of feeder systems.

Biomass feeders are critical components of an energy conversion system and must operate automatically with minimal attention. Feeders have encountered problems because of the nonuniformity of size, moisture content and flow characteristics of common wood residues. Although most feeding problems can be avoided by careful characterization of the feed materials and proper matching of equipment to the required duty, some improvements in feeding equipment for forest biomass are warranted to keep up with the development of energy conversion systems.

Areas of particular interest are wood gasification and fluid-bed combustion. Problems have been encountered by some manufacturers with obtaining feeders that can be used with vessels operated at pressure or under vacuum without air ingress or gas leakage from the vessel. Feeding equipment has been adapted for these purposes, but not without problems with jamming, lack of flow and gas leakage. Feeding problems are most common with coarse residues, such as those used in down-draft gasifiers, and when feeding pressurized systems.

Research is currently underway at B.C. Research under the ENFOR program to improve the technology of bin design and, thereby, improve the ease of recovery of forest biomass from bins by feeder systems. Many feed related problems are due to bin unloading rather than metering and conveying of materials to a conversion system.

B. Scope

The scope of this study encompasses the following principle objectives:

- Establish the present status of technology for biomass feeders.
- Review pulpchip, coal, food, chemical and municipal waste feeders to identify designs that could be adapted to biomass feeding applications and, thereby, improve wood conversion technology.
- Formulate guidelines for selecting biomass feeders for particular applications.
- Identify applications where development or improvement of biomass feeders is warranted.

III. FOREST BIOMASS CHARACTERISTICS

This chapter deals with the physical properties and flow behavior of wood and bark fuels which, in conjunction with the type of energy generation system, determine the types of feeders that should be used. The physical properties of importance to feeder design and that will be considered here are: chemical composition, size distribution, bulk density, abrasiveness, corrosiveness, angle of repose, friction coefficient and stickiness. Flowability and consolidation behavior of wood and bark fuels will be considered for typical circumstances of use.

Of the physical properties, the single most important one is size distribution because of the inherently difficult task of obtaining anything near a consistent size distribution for a wood and bark fuel stream produced as a mill by-product. Related to size is the normally poor flowability of wood residues, particularly hog fuel, which leads to bridging in bins and jamming of conveying and feeding equipment.

A. Physical Properties

Because of the wide variety of species, shapes and sizes of wood and bark fuels that are produced as by-products of the forest products industry, it is not possible to state specific values for physical properties. However, industrial experience has led to a definition of typical ranges of properties and it is these that have been extracted from published literature and summarized here.

When wood residues are prepared and used as fuel they are referred to collectively as hog fuel or hogged fuel, since they have usually had to be reduced in size using a knife or hammer hog. Hog fuel may refer to either a single residue, or a mixture of several types of residues, and, consequently, is not a single fuel with specific characteristics. Hog fuel is an nonhomogeneous fuel and it is this inhomogeneity that precipitates handling and feeding problems.

1. Chemical Composition

The influential contents of wood and bark with respect to feeder selection and operation are resins, intrinsic and extrinsic ash, and moisture. Extrinsic ash is most commonly associated with bark since it can pick up sand and dirt during transport from the forest to the mill. Intrinsic ash is important since it must be removed from the discharged gases, as well as from the bottom of the energy system by ash handling equipment.

Typical proximate analyses of a variety of softwoods and hardwoods are shown in Table III-1. For clean bark and wood no change of proximate analysis occurs as a result of mill operations, although ash content of the materials will increase if inerts are added during handling.

Resinous woods usually have high volatile contents and high heating values; for example, Douglas fir and pine. These resins promote sticking of the residues in feeding equipment and, consequently, cause feeder operating problems and higher maintenance. Feeders for resinous materials should allow easy access for cleaning. Hardwoods are not commonly resinous and, therefore, related feeding problems will not be likely.

The moisture content of residues is strongly influenced by mill processing as shown in Table III-2 for common residues. The range of ash levels also shown reflects the lower values for dirt-free material and the higher values possible in mill situations as a result of handling. Since the amount of dirt present with residues varies according to the handling practices at a mill, ash levels of all residues should be established by analysis for each situation being considered. High dirt content dramatically worsens equipment wear and increases maintenance. Contrarily, the presence of moisture reduces friction and, thus, can help reduce wear.

TABLE III-1

Proximate Analysis of Woods and Barks

Species	Proximate Analysis (Wt %, dry)			Higher Heating Value (MJ/kg, dry)
	Volatile Matter	Fixed Carbon	Ash	
Softwoods:				
Douglas fir - wood	86.2	13.7	0.1	20.47 - 21.40
- bark	70.6	27.2	2.2	23.49
Pine, Ponderosa - wood	87.0	12.8	0.2	21.21
- bark	73.4	25.9	0.7	21.17
Hemlock, Western - wood	84.8	15.0	0.2	18.61 - 20.05
- bark	74.3	24.0	1.7	22.79
Fir, White - wood	84.4	15.1	0.5	18.96
- bark	73.4	24.0	2.6	
Red Cedar, Western - wood	77.0	21.0	2.0	22.56
- bark	86.7	13.1	0.2	20.23
Hardwoods:				
Ash - wood			0.6	19.72
- bark			-	
Beech - wood			0.6	19.98
- bark	75.2	16.9	7.9	17.77
Birch, Yellow - wood			2.7	19.05
- bark	76.5	21.0	2.5	21.40
Maple, Red - wood			1.3	19.33
- bark	78.1	18.9	3.0	18.84
Oak - wood			0.4	19.35
- bark	76	18.7	5.3	20.03
Poplar, Aspen - wood			2.5	19.35
- bark			3.4	20.49

Sources: Arola, R.A.; Pingrey, D.W.; Junge, D.C.; Levelton, B.H.; Corder, S.E.; Huffman, D.

TABLE III-2

Ranges of Moisture and Ash Content for Common Mill Residues

Residue Type	Moisture Content Wt %, wet	Ash and Dirt Content wt %, dry
Bark	25-75	1 -15[b]
Chips	25-60	0.1-2.0
Log Yard Residues	40-60	5 -50
Sanderdust	2-8	0.1-2.0
Sawdust	25-40	0.1-2.0
Shavings	10-20[a]	0.1-2.0
Slabs & Trim Ends	25-50	0.5-2.0

[a] Green shavings can have moisture contents up to 50%.

[b] Clean softwood barks have ash contents of up to 3% while hardwood barks contain usually 5% ash.

Sources: Johnson, R.C.; Levelton, B.H. et al

2. Size Distribution

The size of particles in wood and bark fuels depends on the sources of the several possible residues that make up the fuel mixture. Hog fuel may be a single residue or a combination of the common mill residues that are indicated in Table III-3 except sanderdust which, because of its small size and dryness, is preferentially handled separately, and log yard residues which are frequently not used as a fuel because of high ash content.

TABLE III-3

Size Distribution of Common Mill Residues

Residue Type	Size Range (mm)
Bark, hogged	1-100
Chips, pulp	13-50
Hogged Fuel	1-100
Log Yard Residues	> 100
Sanderdust	0.002-1.0
Sawdust	1-10
Shavings	1-13
Slabs & Trim Ends	> 100

The grain structure of wood promotes the formation of elongated piece sizes during comminution in hogging and chipping equipment. These particles may not fall within the size categories indicated for mill residues and are frequently not well handled by sieving equipment. It is inevitable that some elongated particles, or sticks, will pass through all storage and handling systems and reach the feeder for an energy conversion system. The feeder must be designed to cope with the occasional undesired feed materials that penetrate the feed preparation system, or to be supported by redundant units that enable operation with only a minor disruption when feeder failure occurs.

Prior to selection of any handling and feeding equipment, a thorough sampling of the wood residue fuel should be conducted. Size characterization of these samples should determine the range of piece sizes, as well as the maximum possible piece size. Solid pieces or frozen lumps that are too large for the energy conversion system should be either removed from the fuel upstream of the feeder with appropriate screening equipment or processed to reduce piece sizes to acceptable values.

Since hog fuel frequently contains metals and other foreign materials that cannot be accommodated by a feeder or energy conversion system, equipment should be installed to screen out all objects which can cause equipment failures.

3. Bulk Density

The variability of the composition of residue fuels can easily lead to use of incorrect densities for sizing feeder equipment. The bulk density of hog fuel depends on the size, shape and moisture content of individual fuel components, the species of the wood residues and the proportions of wood and bark.

The bulk density of any residue can be estimated simply by using the following relationship:

$$\underset{(\text{kg/m}^3)}{\text{Bulk Density}} = \left(\frac{\text{Volume Solid Wood}}{\text{Total Volume}}\right) \times \text{Basic Wood Density (kg/m}^3) \times \left(\frac{100}{100 - \%\ \text{Moisture Content, Wet Basis}}\right)$$

The volume fraction of solid wood in a bulk sample for common wood residues is given in Table III-4 along with typical ranges of bulk density. Basic wood density in units of kilograms of oven-dry wood per cubic meter of solid wood have been tabulated by Dobie and Wright, and Smith, W.J. for the western coast and Kennedy et al for the eastern coast.

TABLE III-4

Volume Fractions of Solid Wood and Bulk Densities

for Common Mill Residues

Residue Type	Volume Solid Wood (ft^3 SWE/unit)	Volume Fraction Solid Wood (m^3/m^3)	Typical Bulk Density (kg/m^3)
Bark, hogged	73 - 85	0.37-0.43	160 - 480
Chips, compacted	80	0.4	160 - 400
uncompacted	70 - 72	0.35-0.36	160 - 350
Hogged fuel	66 - 73	0.33-0.37	200 - 400
Planer shavings	45 - 50	0.23-0.25	110 - 140
Sanderdust	-	-	160 - 200
Sawdust	72 - 80	0.36-0.40	200 - 350

4. Abrasiveness and Corrosiveness

Most of the abrasiveness and corrosiveness of wood and bark fuels is due to the presence of foreign materials.

Hog fuel can be extremely abrasive if it contains admixed soil and sand, usually associated with the bark component. If in significant concentration, these abrasive materials can quickly wear moving components of most feeders. The preferable cure for this problem is screening of the hog fuel to reduce sand and dirt content, although another alternative is the use of slow moving feeders, possibly with friction-reducing or sacrificial wear surfaces.

Corrosion of feeder systems can be a problem when handling the residues of high salt content that result from ocean-transport of logs. Moisture, of course, will promote some corrosion.

5. Angle of Repose

Most wood residue fuels have steep angles of repose, often from 40° - 60° to the horizontal for free falling materials put in piles and against walls. Lightly compacted hogged materials placed in bins frequently can form near vertical, and sometimes overhanging, surfaces when part of the material is removed. Both of these behaviors require special consideration when designing bin discharge outlets and feeder inlets to ensure a continuous flow of material.

Some fuels in bins and piles have the ability because of particle sizes, moisture content and bin discharge design to bridge over wide spans, causing a serious interruption in material flow. Compacted fibrous wood residues have a strong tendency to bridge and feeder inlets must be designed with equipment to collapse bridges or so that no stable bridges can form against bin walls.

6. Friction Coefficient

Friction is the cause of wear in feeders and increases the power required for operation. Very little information is available stating the friction coefficient of wood residues on metal and other surfaces common to feeder systems. Shigley gives a sliding friction coefficient of 0.16 for wet wood on steel, and a value of 0.2 - 0.35 for dry wood on steel. The FMC Corporation suggests a coefficient of 0.35 - 0.45 for wood chips on steel in a flight conveyor. Without more specific data, a friction coefficient of near 0.4 appears realistic for most residues in feeder systems.

The presence of sand and soil with wood residues can markedly increase friction and increase wear. The use of low-friction material, such as ultra-high molecular weight polyethylene, will lower the friction coefficient.

7. Stickiness

Stickiness is dependent on the resin content and the moisture content of the wood residues. Resin content was discussed previously under the heading of chemical composition. Moisture can cause sticking of fine materials to surfaces in poorly cleared areas of feeders such as near the base of the vanes in a rotary feeder and in uncleared areas of conveyor systems.

B. Flow Behavior

Flow behavior of solids is complexly related to size, shape, size distribution, density and several other physical characteristics and must generally be assessed empirically and qualitatively. The qualitative nature of flowability makes it impossible to state categorically what the flowability of a certain wood residue will be under all conditions. Some general comments are the best that is possible at present.

1. Flowability

Table III-5 shows general flowability characteristics of common mill residues. All wood residues can, under certain circumstances, be sluggish materials prone to hangups, bridging and consolidation. The relative ease of handling ratings given in the table are general guides and must be used with discretion since local conditions can reverse some of these.

Flowability of wood residues can be improved by agitation such as is done with bin activators. Dry residues consistently flow more easily than wet residues because of their lower shear strength.

TABLE III-5

Shape and Flowability of Common Mill Residues

Residue Type	Shape	Relative Ratio, Surface to Volume	Relative Ease of Handling 1-Best 6-Worst	Flowability
Bark, hogged	Irregular lump	1	3	Sluggish
Chips	Irregular platelet	1	1	Flows
Hogged fuel	Fibrous, irregular lumps	-	2	Sluggish
Planer Shavings	Curly wafer	5	6	Very Sluggish
Sanderdust	Spherical, cubic	10	5	Very Sluggish
Sawdust	Cubic	6	4	Sluggish

Sources: Junge, D.C.; Levelton et al

2. Consolidation

Wood residues consolidate upon application of pressure. Consolidation occurs with depth in piles and bins, as well as during extrusion-type conveying, and results from mechanical intertwining of the fibrous residues. Consolidation leads to worsened problems with bridging and, of course, reduces flowability.

Consolidation can also occur because of freezing of water in and between wood residues that unites them into a large mass. This can be a serious problem in Canadian climates.

IV. FEEDER SYSTEMS

A. General

Feeders as considered in this study encompass equipment that withdraws material from temporary storage and transports to and discharges into an energy conversion unit. The feeder must therefore be effective at recovering material steadily from storage, regulating the flow of material, and discharging and distributing the material inside the conversion unit. One piece of equipment can rarely accomplish all of the above tasks. Instead, up to three pieces of equipment must be used, one each for metering, conveying and distribution. Emphasis in this study is placed on metering and conveying feeders that are suitable for emerging wood conversion systems such as fixed and fluid bed gasifiers. These feeders may or may not distribute materials in some manner within the conversion unit as an inherent characteristic. Distributors may be added to most feeder systems.

Generally, there are two types of feeders, these being volumetric feeders and gravimetric feeders. Virtually all feeders in common use for wood residues are volumetric feeders, which regulate the volume of material conveyed. Gravimetric feeders regulate the rate of transport according to weight and are used where accurate feed rates are essential. These will be discussed as the designs arise in the following sections since they may find applications in feeding wood residues in some circumstances.

This chapter discusses the general functions of feeders and the types of feeders that are used for wood residues, coal and other materials that have physical and flow characteristics that are comparable to wood residues. Detailed discussions of each feeder design are postponed until the following chapter.

B. Functions of Feeders

1. Metering

Both volumetric and gravimetric feeders can be effective at regulating the flow rate of material fed to a conversion system. However, gravimetric feeders can meter within plus or minus 2% of the desired feedrate, whereas volumetric feeders are much less accurate, particularly when the bulk density and the moisture content of the material are variable.

The metering system may be controlled manually or automatically, the acceptability of each being dependent on the size of the unit, the constancy of the fuel characteristics and the steadiness of the load on the conversion unit. An automatic control system must be as simple and rugged as possible and may alternately operate using on-off or proportional feedback controllers. The control system must be considered as an integral part of the feeder and be compatible with its conveying characteristics.

Regulation of feedrate for both volumetric and gravimetric feeders is accomplished either by controlling the size of the bin opening while retaining an essentially constant discharge velocity of solids, or by controlling the discharge velocity of the solids while retaining a constant bin opening. In the case of volumetric feeders, feedrate is based on average volume flowrate. Similarly, mass flowrate is used to control gravimetric feeders. Practical limits of velocity and size of the bin opening dictate the combination of each of these variables that must be used. On-off control systems function by varying the average flowrate over a long period since actual flowrates of batches of fuel remain constant.

The metering portion of the feeder should extract material through the entire bin opening and produce near uniform flow of material through the bin to the outlet. The type of feeder system and the design of the bin and bin opening will influence the flow pattern of materials in the bin and determine whether flow is non-uniform or uniform. Uniform flow (mass flow) is far more preferable than localized flows that lead to funnel flow, rat-holing and bridging.

2. Conveying

The metering portion of the feeder system regulates the flow of materials and discharges into conveying equipment that transports these materials to and discharges them within the conversion system. The metering and conveying functions may or may not be combined in one piece of equipment classified commercially as a feeder. Feeders can, therefore, be either conveying or non-conveying types. Depending on the layout of the energy conversion system, the requisite entry point of the fuel for proper functioning of the conversion system and the design of the feeder, there are obviously many feeder system layouts. Some feeders such as rotary feeders may rely on gravity and a directing chute to convey materials, while others such as screw feeders both meter and convey. Chapter VI covering Types of Feeders systematically discusses the functional capabilities of each design, indicating whether the design has self-metering and/or self-conveying capabilities.

3. Distribution

Most commercial feeders are not capable of distributing material across the area of the energy conversion system and some separate distributing equipment must be used. Distributors are widely used in boilers to achieve a near uniform distribution of fuel across grates. The need for a distributor increases with the cross-sectional area of the conversion system; for a cross-sectional area of 1 m^2 a distributor may not be required, while a distributor would be essential for a cross-section of 30 m^2.

Commercial feeders without distributors use a top-mounted feeder and rely on gravity to form a symmetric pile in the desired area, while those using distributors have wall mounted units and mechanical flingers or air streams to spread material in a near uniform pile. The discussion in Chapter VI identifies the distributing capability of feeders and associated installation limitations.

C. Types of Feeders

The scope of the survey of feeders for this study included most solid fuels and materials that are difficult to handle. The consideration of feeders for materials other than wood residues is intended to identify feeders that, although not presently used for wood residues, would likely function as well as or better than conventional feeders when adapted to this duty. Only those feeders that appeared appropriate to handling wood residues were considered.

A comprehensive list of commercially proven and newly developed feeders for a variety of solids handling applications was developed. The designs were evaluated for their ability to meter, convey and distribute solids, and were associated with common handling applications (Table IV-1). In this table it is evident that most feeders are simply conveyors with an added metering system. In most cases a gate feeder is used in conjunction with a conveyor design; examples are Apron, Belt, Flight and Vibrating conveyors. This distinction of capabilities, although possibly exacting, is necessary to clearly identify the capabilities of feeder designs and to encourage the design of feeders as integrated systems.

It is evident from Table IV-1 that no single feeder satisfies all functional requirements.

Usually, feeders listed in Table IV-1 can be mixed to achieve the desired functions. For example, one might use a gate feeder at

TABLE IV-1

FEEDER TYPES, FUNCTIONS AND COMMON MATERIALS HANDLED

Feeder Type	Operating Principle	Functions			Common Materials Handled
		Self-Metering	Self-Conveying	Self-Distributing	
1. Apron Feeder	Carries material on overlapping pans	No	Yes	No	All heavy abrasive materials - coal, mineral ores plus 1 cm in size. Sometimes used for wood chips.
2. Belt Feeder	Troughed or flat moving belt	No	Yes	No	All minus 10 cm non-sticky materials-coal, granular materials, wood residues.
3. Feed Chute	Simple ducting of material using gravity	No	Yes	No	All materials. Feeder must have suitable cross-section and no sudden directional changes.
4. Flight Conveyor Feeders	Flights sliding in trough	No	Yes	Yes	Any material that is not stringy - biomass, mineral ores, powders.
5. Gate Feeders	Guillotine gate	Yes	No	No	Used with 1, 2, 3, 4, 12 and 14 to meter flow. Granular free-flowing materials. All wood residues from overhead conveyor. Wood residues from storage when used with activator.
6. Linear Pocket Feeder	Flights sliding in tube	No	Yes	No	Coal sized to minus 2 cm. Developed to fuel pressurized gasifiers. Has potential for wood residues.

TABLE IV-1 (continued)

FEEDER TYPES, FUNCTIONS AND COMMON MATERIALS HANDLED

Feeder Type	Operating Principle	Functions			Common Materials Handled
		Self-Metering	Self-Conveying	Self-Distributing	
7. Lock Hopper	Feed bin with infeed and discharge valves	No	Yes	No	All materials. Has been used for wood residues with top size of 15 cm.
8. Pneumatic Feeder	Pneumatic Conveyor	No	Yes	Yes	Sanderdust and wood residues up to 8 cm top size. Good for wood chips, not preferred for hog fuel. Most fine non-abrasive materials.
9. Ram Feeder	Enclosed reciprocating ram	Yes	Yes	No	Minus 8 cm biomass and granular materials - chips and hog fuel, but no solid blocks.
10. Rotary Feeder	Enclosed rotating vanes	Yes	No	No	Dry wood chips, dry fine wood, coal, mineral ores, salt. Most low-moisture minus 5 cm materials.
11. Rotary Plow Feeder	Plow running over rotating table	Yes	No	No	Unlimited types of biomass and granular materials - good for sluggish, matting solids.
12. Rotary Table Feeder	Rotating table below bin	Yes	No	No	Wood chips up to about 5 cm. Bin unloader.

TABLE IV-1 (continued)

FEEDER TYPES, FUNCTIONS AND COMMON MATERIALS HANDLED

Feeder Type	Operating Principle	--------------Functions------------			Common Materials Handled
		Self-Metering	Self-Conveying	Self-Distributing	
13. Screw Feeder	Enclosed rotating helix	Yes	Yes	No	Minus 8 cm wood residues and granular materials. Stringy materials not suitable.
14. Vibrating Feeder	Vibrating trough	No	Yes	No	Wood residues, mineral ores, food garbage. All non-sticky materials up to 20 cm in size.

the base of a bin to regulate flow to a vibrating feeder which, in turn, discharges into a feed chute and the conversion system. This conceptual design process assembles a series of defined unit operations to develop a system with the desired performance characteristics.

V. SURVEY AND ASSESSMENT OF WOOD FEEDER APPLICATIONS

To form a basis for evaluation of forest biomass feeders and feeders and feeders that could be adapted from other industries, a survey of feeders used on various energy conversion systems was conductd. These systems included boilers, fluid-bed and multiple chamber combustors, suspension burners, fixed-bed and fluid-bed gasifiers and pyrolyzers. Representative manufacturers and users of these systems were contacted in hopes of providing an overview of feeders currently in use with these systems pertaining to types of feeders being used, effectiveness of these feeders, characteristics of fuel, and problems being encountered which are inherent to the type of energy conversion systems in question.

A. Boilers

Packaged boilers, which are usually limited to capacities of somewhat less than 100 GJ/h, are usually fueled by biomass which range in size from 8 cm to fine sawdust and in moisture content from 15% to 50%.

Two general methods of feeding are applied to these boilers, underfire feeding and overfire feeding. Underfire feeders currently in use include reciprocating ram and screw feeders and are generally limited to systems with capacities less than 30 GJ/h.

Package boilers which are designed for overfire feeding usually incorporate feeding system comprised of at least two feeders, one to meter fuel, and the second to actually feed the material into the combustion chamber. In all cases examined, a screw feeder was used to meter the fuel into the primary feeder. The primary feeders included screw, pneumatic, and feed chute type feeders, and in one case an intermediate belt conveyor was inserted between the metering screw feeder and the primary feeder.

Most manufacturers offer simple on-off controls for the feedrate, although proportional controls are available for improved load-following capabilities. Underfire systems are characteristically better for steady load rather than varying load applications.

Existing feeders for packaged boilers appear satisfactory for most applications. Since the boilers run at slight vacuums no serious problems exist with air ingress or leakage of fumes. Pneumatic systems offer the potential to operate the furnace with slight positive pressures if desired.

Boilers larger than 100 GJ/h are suited to field fabrication. These units are available with a wide variety of feeder systems including flight conveyor feeders, screw feeders, rotary valve feeders and vibrating feeders. Spreader stokers are used widely, relying on pneumatic and mechanical equipment for fuel distribution. Pneumatic distribution systems are preferable for wood residues since they are less vulnerable to plugging and require less maintenace than mechanical distributors. Dutch-oven boilers are also widely used and have the advantage of low emissions of particulates for wood residues although at the expense of poor load following capability. These boilers do not require fuel distributors. For both spreader-stoker and Dutch-oven boilers simple feed chutes are adequate for directing feed into the furnace. The function of the feeder system is primarily to meter the feed and to ensure an adequate fuel supply.

Boiler feed systems are well proven and with satisfactory design will function effectively. The feeding problems that are encountered usually can be eliminated by proper design of materials handling equipment and feed chutes. Most problems are associated with oversize residues or foreign materials plugging the feed chute at constrictions or at mechanical spreaders. The problems with foreign materials and oversize residues could easily be avoided by improved size classification and metal detection.

B. Fluid-bed Combustors

The single most important characteristic of the fluid-bed combustor design pertaining to feeders is whether the combustor operates under conditions that produce a slight vacuum in the freeboard region above the fluid-bed, or whether the system operates under positive pressures. The former case allows for simplified design of the feeder systems and gives considerable latitude to the type of feeder that can be used. However, the latter case imposes the criteria of adequate sealing in the feeder system to ensure combustion gases do not leak from the reactor.

Typically, fluid-bed combustors are available in capacities up to 130 GJ/h and are fueled by residues ranging in size from minus 0.6 to minus 8 cm with moisture contents up to 65%.

The importance of distribution of fuel across and within the fluid-bed increases in some proportion to bed volume. Non-uniform heat release will occur in non-uniformly fed fluid-beds and cause operation irregularities and worsen control of the unit. Fluid beds are inherently well mixed and have a thermal capacitance that makes them tolerant to nonuniform feeding compared to fixed-bed designs.

Fluid-bed combustors commonly use either rotary valve, pneumatic or screw feeders. The problems experienced by users of fluid-bed units have been jamming of metering systems with foreign materials such as rocks, metals and oversize residues, and leakage from rotary valves attached to systems operated at positive pressures.

Several feeders have been applied to fluid-bed coal combustors. These feeders are usually for combustors operated at negative pressures and were simple adaptations of feeders used for conventional boilers. Pressured fluid-bed combustor systems for coal most commonly utilize either lock-hoppers or rotary air lock valves to seal the feed system, and pneumatic feeders, screw feeders or feed chutes to transport coal into the combustor.

In summary, existing biomass feeders for fluid-bed combustors are satisfactory when the unit is operated under slight vacumm conditions. Problems do exist for these units, but they are not severe. Few feeders are proven for feeding biomass into pressurized combustors and an improvement of existing rotary valve or screw feeders, or development of a new design would be beneficial.

C. Multiple Chamber Combustors

Multiple chamber combustors are available in capacities of up to 160 GJ/h and are fueled by residues with moisture contents ranging up to 65% and size with particle sizes ranging from sawdust to 10 cm.

Feeder systems used by major manufacturers of multiple chamber combustors include hydraulic rams and screw feeders for underfire feeding and metered flow into a feed chute for overfire feeding. Underfire feeding systems operate at higher mechanical loads because of resistance to motion of the fuel bed. These feeders produce an advantageous arrangement of the drying, pyrolysis and combustion zones in the fuel bed. Overfire feeding systems are prone to higher carryover and, except for special designs, when feeding wet fuel may cause flame instability on the upper surface of the fuel bed.

The main problem reported for underfire screw feeders is the common one of jamming with oversize residues and foreign materials. This can be avoided by proper screening of the residues.

Hydraulic rams are cyclic batch feeders that will cause minor cyclic variation of the furnace operation. No users have reported any problems associated with this characteristic of ram feeders. Ram feeders preferably should be preceded by a metering device to minimize shear of residues between the plunger and the ram tube. Ram systems can be obstructed by oversize residues and metals, but this is common to all feeders. Rams can be designed to shear the odd oversize piece of solid wood that may penetrate past screening equipment. Ram feeders do not feed stringy residues well.

The multiple chamber combustors considered in the survey operate with the furnace below atmospheric pressure, avoiding problems with any leakage of combustion gases, but causing ingress of air through non air-tight joints. Underfire feeders are advantageous in this respect since air ingress is not a problem. Overfire feeders are commonly enclosed to reduce tramp air flow and improve control over combustion conditions.

Users and manufacturers of multiple chamber combustors have expressed satisfaction with existing designs of biomass feeders, except for minor mechanical failings.

D. Suspension Burners

Suspension burners are available in sizes ranging up to 65 GJ/h. These systems are fueled by fine residues less than 0.3 cm in size and with moisture contents of less than 15%. These energy conversion systems all use pneumatic feeders which are themselves fed by rotary, screw, vibrating, or airlock feeders. This design has proven to be an efficient means of injecting combustion air and fuel into the combustion chamber, and is an essential part of the combustor. No serious problems exist for the feeder systems used by the surveyed manufacturers. The uniformity of pulverized residues used by suspension burners contributes substantially to the ease of handling.

E. Fixed-Bed Gasifiers

Only a few commercial wood gasifiers are presently operational with the result that few have gained experience with continuous operation. These units are available with capacities up to 53 GJ/h. Fuel characteristics vary dramatically with each manufacturer; ranging from 15 cm diameter by 15 cm long blocks with moisture contents less than 50% to minus 5 cm chips which have moisture contents of less than 15%.

To avoid leakage of toxic gases and to simplify the configuration of the feeder connection to a gasifier most manufacturers design their gasifier vessel to operate at a slight vacuum by appropriate placement of forced-draft and induced-draft fans. This approach to gasifier design has some limitations. Improved chemical reaction rates could be achieved by operating at higher pressure, especially with advanced systems using oxygen and steam injection to produce medium heating value gas. Operation at elevated pressure would also reduce the size of vessels and piping needed for gasifiers.

The manufacturers of fixed-bed gasifiers with the most operating experience, Duvant and Imbert, use batch feeding systems that are not attractive for continuous unattended operation. The advantage of batch feeding is its insensitivity to particle size. An observed problem with batch feeding in the Imbert unit is the need to open the gasifier, allowing escape of pyrolysis and gasification gases and necessitating the use of appropriate venting. Discharge of gases occurs even though the unit is operated with the air inlet at the throat of the gasifier under vacuum. The remaining gasifier manufacturers use either rotary valves, enclosed screw feeders or hydraulic rams with upstream metering equipment.

One evident problem for feeding downdraft gasifiers is the upper particle size suggested for satisfactory operation. Inexpensive screw-type chippers used for producing fuel chips tend to pass butt-ends that are equal to the log diameter and up to 15 cm long. Solid wood of this size could not be passed by screw feeders or rotary feeders and could cause problems with ram feeders. Power requirements for feeders able to shear such large wood chunks would be large, while the expense of proper screening equipment would be unacceptable for small gasifiers up to, say, 5 GJ/h in capacity.

All the continuous feeders surveyed have functioned successfully, although all are vulnerable to jamming and gas leakage under certain conditions. The most popular of these feeders is the rotary valve. This feeder must be oversized to prevent bridging problems in the inlet chute to the feeder and across the valve pockets. Screw feeders and ram feeders rely on compressed wood to form a seal and prevent gas leakage and, therefore, are susceptible to poor sealing, especially with coarse wood residues, and to jamming.

The problems with continuous feeders are not limiting development of fixed-bed gasifiers, but are affecting the choice of feed preparation steps. Venting of gases from near feeder connections is a common design feature to avoid problems with gas leakage. Development of an improved continuous feeder, or an investigation of sealing properties of ram and screw feeders operated with coarse residues would benefit the design of fixed-bed gasification systems.

Batch feeding of fixed-bed gasifiers using a lock-hopper have encountered problems with spillage, tar accummulation on the gate valve connecting the lock hopper and the gasifier, and bridging in the lock hopper. An automated batch feeder has been incorporated into the Imbert gasifier supplied to Snowshoe Industries in Fort

Providence, NWT, and work is currently under way by the purchaser of the system to resolve feeding problems caused by poor operation of a pile height sensor in the gasifier. Spillage of residues is a problem with this unit.

Batch feeding is presently the only practical means of feeding coarse fuel chips made by inexpensive chippers, since piece sizes are greater than that acceptable for continuous feeders. Improved automated batch feeding systems would be of substantial benefit to commercial acceptance of down-draft biomass gasifiers. Technology on batch feeding could be transferred from experience with feeding coal to gasifiers.

F. Fluid-bed Gasifiers

As with fixed-bed gasifiers, few systems are commercially operational, and consequently, it is difficult to evaluate with any certainty the practical advantages and disadvantages of feeders for these units. Fixed-bed gasifiers are available in capacities up to 250 GJ/h and are fueled with residues having moisture contents less than 55% and sizes ranging from minus 0.6 cm to minus 8 cm.

Since fluid-bed gasifiers may operate with a positive pressure in the reactor, proper sealing is an important consideration in feeder design.

Currently, manufacturers use feeder system designs which include rotary ram and screw feeders, including the Stake Technology feeder which is a combination of the reciprocating ram and screw feeder design.

As discussed previously for fluid-bed combustors, development of a new continuous feeder or improvement of existing rotary valve, ram, or screw feeder designs would benefit wood gasification technology. Some benefit could be derived by considering feeders that have been applied to pressurized coal gasifiers. These feeders include batch feeders, high pressure twin-screw feeders and pneumatic feeders. Caution must be used in assessing the suitability of these feeders for wood residues because of the better flow behaviour of crushed coal.

Investigation of the sealing behaviour of wood residues when compressed within screw and ram feeders would assist in the design of better units for feeding biomass against pressure. This investigation would also lead to better matching of feeders to certain residue types and pressure applications.

G. Pyrolyzers

No significant reports of operating experience are available on any of the pyrolysis systems currently being manufactured. Those manufacturers contacted reported a wide range of specifications of fuel characteristics for the pyrolysis units ranging from minus 20% to minus 60% moisture content and from fine sawdust to minus 15 cm in size.

For the most part, manufacturers of pyrolyzers have designed their systems with screw feeders to inject residues into the reactor. In one case, the feed system consists of a vertical feed chute augmented by two butterfly valves to prevent leakage of gas out of a rotary reactor.

The main problems which would be encountered with feed systems of pyrolyzers are similar to those encountered with gasifiers, namely jamming of the feeder with oversize and foreign material, and adequate sealing to prevent gas leakage.

VI SURVEY AND EVALUATION OF FEEDER DESIGNS

A. Summary

A total of fourteen general types of feeders were considered. These included all designs commonly used to feed wood residues to conventional conversion systems, some of them such as feed chutes being trivial cases, as well as new designs being developed to feed coal and other materials, often to pressurized reactors.

The evaluation and assembly of data for all the feeders was standardized to the extent possible with information supplied by manufacturers and obtained from published literature. For types of feeders that are marketed with only minor differences by several companies, the discussion of the feeder type is done generically using designs by particular manufacturers as examples only. For types of feeders such as screw feeders that are available in many arrangements each often with substantially different performance characteristics, generic or unique designs of screw feeders are discussed individually.

The discussion of feeders emphasizes those types which may be used to feed pressurized vessels. If no experience has been obtained with feeding wood residues, the type of materials handled and the operating experience gained with these materials was summarized.

Table VI-1 summarizes some of the information obtained for all the feeders considered. The feeders listed as being able to feed across a zero differential pressure are the types which are used for conventional wood conversion systems operating with slight positive or negative pressures and for which gas leakage or ingress is not a problem.

Feeders available for use on pressurized conversion systems are: lock hopper feeders; linear pocket feeders; piston feeders; rotary feeders and screw feeders. Some of these feeders were developed for feeding wood chips and sawdust to pulping processes and are, therefore, proven equipment for these materials at differential pressures up to about 1,030 kPa. Feeders for higher differential pressures are available, but few have been used for wood residues. Many of the designs originated from a development program funded by the U.S. Department of Energy which was concerned with feeders for pressurized coal gasifiers. These designs reflect the granular nature and particle sizes of coal feedstocks. The potential for use of these high-pressure feeders for wood residues is considered in the text.

TABLE VI-1

Comparison of Feeder Characteristics

FEEDER TYPE	STATUS*	COMMON FEEDS	SUITABLE SIZES OF WOOD RESIDUES (cm)	DIFFERENTIAL PRESSURE (kPa)	COMMENTS
Apron Feeder	C	>1 cm, dense abrasive materials	1 - 8	0	-Inappropriate for wood residues -High Cost
Belt Feeder	C	all types	<10	0	-Best for non-sticky, non- abbrasive materials -Inclines <15° -Belt cleaners preferred
Feed Chute	C	all types	all sizes	-	-Avoid direction changes -Diverging sides preferred
Flight Conveyor Feeder	C	all types	all sizes	0	-Poor for stringy residues -Inclines <35° -Use with high molecular weight polyethylene trough coating
Gate Feeder	C	all types	<5 cm	0	-Must be used with other feeders or flow-inducer for wood residues

TABLE VI-1 (continued)

Comparison of Feeder Characteristics

FEEDER TYPE	STATUS*	COMMON FEEDS	SUITABLE SIZES OF WOOD RESIDUES (cm)	DIFFERENTIAL PRESSURE (kPa)	COMMENTS
Linear Pocket Feeder	D/E	<2 cm coal	unknown	3,450 (projected to 10,450 kPa)	-Prototype tested with coal -Not suitable for stringy and sticky residues
Lock Hopper Feeder	C	all types <5 - 10 cm	<15	3,200 (8,500 max.)	-Feeders available with gravity, pneumatic and screw discharge -Problems with jamming valves, bridging and venting of gases
Pneumatic Feeder	C	all types, <5 cm	<5	70	-Requires use of rotary air lock -Poor for abrasive or stringy material -Good arrangement flexibility -High noise and power levels -Good for conveying long distances

TABLE VI-1 (continued)

Comparison of Feeder Characteristics

FEEDER TYPE	STATUS*	COMMON FEEDS	SUITABLE SIZES OF WOOD RESIDUES (cm)	DIFFERENTIAL PRESSURE (kPa)	COMMENTS
Ram and Piston Feeder					
-Ram Feeders	C	<5 - 7.5 cm coal, wood	<7.5	3	-Best for underfire stoker -High power requirement to shear residues -Poor for fine particles
-Piston Feeders	D/E	<5 cm coal	<,5 (estimate)	3,500 (10,000 max.)	-No tests have been conducted with wood residues -Feeders developed for pressurized coal gasifiers -Feeders by Lurgi and Ingersoll-Rand appear best for residues
Rotary Feeder					
-General Duty	C	<7.5 cm wood chips, hog fuel	<7.5	0	-Used for metering -Problems with jamming -Poor for wet, sticky residues

TABLE VI-1 (continued)

Comparison of Feeder Characteristics

FEEDER TYPE	STATUS*	COMMON FEEDS	SUITABLE SIZES OF WOOD RESIDUES (cm)	DIFFERENTIAL PRESSURE (kPa)	COMMENTS
-Low/Medium Pressure	C	<5 cm, wood chips, sawdust	<5	1,030	-Requires venting -Wear increases leakage -Problems with jamming -Low space requirements
-High Pressure	C	<2.5 - 5 cm coal, wood chips	<5	2,400	-Most experience with sized coal, <2.5 cm -Suffers from problems noted above -Kamyr markets unit for hydro transport -Not attractive for most conversion systems
-Rotary Plow Feeder	C	<30 cm, coal	<30 (estimate)	0	-No installations for wood residues -Rugged design -Used as bin unloader
-Rotary Table Feeder	C	all types	<5	0	-Used successfully to unload wood chips from bins

TABLE VI-1 (continued)

Comparison of Feeder Characteristics

FEEDER TYPE	STATUS*	COMMON FEEDS	SUITABLE SIZES OF WOOD RESIDUES (cm)	DIFFERENTIAL PRESSURE (kPa)	COMMENTS
Screw Feeder					
-General Duty	C	<7.5, wood chips, hog fuel	<7.5	0	-Poor for stringy residues -Well proven
-Low/Medium Pressure	C	<5, wood chips	<5	1,030	-Units used for metering and de-watering chips for processing -Poor for stringy residues -Several designs available
-High Pressure	C/D/E	<0.6 - 5, wood chips,	<5	2,400 - 20,000	-Poor for stringy residues -Problems with jamming -High cost
Vibrating Feeder	C	all types	<20	0	-Problems with powders -High capacities -Low power

*Key for Status: C - Commercial; D - Demonstration; E - Experimental

For feeding wood residues across differential pressures in excess of roughly 1,000 kPa, the prime candidates are:

Linear pocket feeder
Lock hopper feeder
Lurgi Schlepper piston feeder
Ingersoll-Rand co-axial piston feeder
Rotary feeder
Werner Pfleiderer co-rotating screw feeder
Koppers plug screw feeder
General Electric screw feeder
C E Bauer Pressafiner (screw feeder)
Stake Technology co-axial screw feeder
Ingersoll-Rand reciprocating screw feeder

B. Apron Feeder

1. Design and Operating Principle

An apron feeder consists of an endless apron formed by overlapping pans. The pans move on head and foot terminal rollers which provide support and a means of driving the feeder. Intermediate support may be required for long feeders. The pans are attached to two or more strands of chain and provide the conveying medium. Pan sides of various design are usually attached to the pans to prevent spillage of material from the feeder.

In operation, the apron feeder is placed below a suitably sized bin outlet. Material is fed onto the apron by the force of gravity and is conveyed to the discharge end of the feeder. (Figure VI-1). Stationary skirt plates or hopper sides confine the material to the apron and provide the necessary depth of bed.

Two methods are used to control the rate of feed: the bed depth on the conveyor, limited by a bin gate; and feeder speed, controlled by a variable speed drive.

2. Performance Characteristics and Costs

Apron feeders are suitable only for conveying material and do not perform metering or distributing functions. They are generally used for high density material (greater than 1,600 kg/m^3) and operate at feed rates of greater than 100 tonnes per hour. Power requirements for apron feeders are comparable to chain and drag conveyors and roughly twice that of belt conveyors, typically between 0.1 and 0.2 kw per tonne per hour.

Generally apron feeders are used in heavy industries such as steel and mining. Materials of greater than 2 cm in size are best suited to feeding by apron feeders. Smaller sized material can also be fed with these feeders, although this is not desirable.

It is important that apron feeders are properly maintained during their operation or long shutdowns may result. Proper lubrication and chain tension adjustments are of prime importance. Depending on duty, replacement of chain and pans are required every three years.

Apron feeders are one of the most expensive feeders on a per unit capacity basis since they are built rugged to

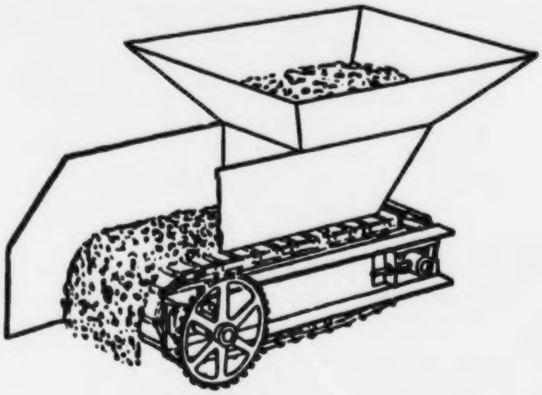


FIGURE VI-1 APRON FEEDERS

withstand forces associated with high density material. Typically, apron feeders cost between $750 to $ 3,000 per tonne per hour capacity.

3. Applications

As previously mentioned, apron feeders are generally used in heavy industries. Because of their high capacities and poor capability for handling fine moist particles, apron feeders are not suitable for handling wood residues.

Imbert supplied an apron feeder for the wood gasifier purchased by Snowshoe Industries Ltd. of Fort Providence, NWT. This unit feeds coarse chips, produced using a screw-type chipper, to the gasifier under cycle time control. The gasifier is fed with batch-quantities using a lock hopper. The feedrate is under automatic control activated by a pile-height sensor mounted within the gasifier.

Because of bridging in the feed bin the apron feeder feeds erratically. The quantity of material put in the pockets of the feeder is poorly controlled by a hinged gate.

4. Manufacturers

Apron feeders may be obtained from many companies marketing material handling equipment. These would include:

Stephens Adamson Ltd.
F.M.C. Canada Ltd.
Barber-Green Company
Iowa Manufacturing Company

C. Belt Feeder

1. Design and Operating Principle

A belt feeder consists of an endless belt, with a heavy rubber cover on the carrying side, operating between head and foot pulley terminals (Figure VI-2). Belt feeders may be classified by the type of support used to carry the belts between the terminal pulleys. Idler belt feeders use freely rotating rollers to support the belts. The spacing of the rollers are dependent upon belt width and material properties, usually every 1.3 to 2 meters for wood residue. Idlers may be orientated such that the cross section of the belt is flat or troughed (Figure VI-3). Troughed belts are used to increase capacities and may have side slopes as high as 45°.

Slider belts are supported by continuous bed plates between the terminal pulleys. On long feeders it is advisable to provide a gap in the bed plate every 3 to 4 meters to break the vacuum created by the belt sliding over smooth steel. These belt feeders amy also have flat or troughed cross sections (Figure VI-4).

Belt feeders are placed below bin openings or feed chutes and material is loaded by gravity. Loading rates are generally cntrolled by bin gates or bin activators. Skirt plates, possibly with adjustable rubber strips along their lower edges, may extend along a partial length of the feeder to prevent spillage and provide proper bed depth.

Belt feeders may either feed material volumetrically or gravimetrically. Feedrates of volumetric belt feeders are fixed by belt speed and belt width and vary only with loading rates. Gravimetric belt feeders differ from volumetirc feeders in that they have a weighing plate section along the feeder which monitors the weight of material passing over it. With a proportional feed back control the belt speed is varied to provide a constant mass feedrate. Otherwise, both volumetric and gravimetric belt feeders have the same design and performance characteristics.

Belt feeders may be configured in horizontal or ascending paths or a combination of both (Figure VI-5). For combination configurations one or two belts may be used, although it is preferable to use one belt to keep costs as low as possible.

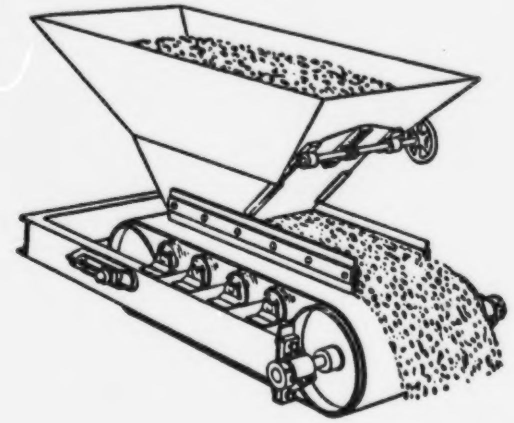
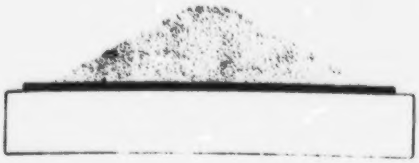
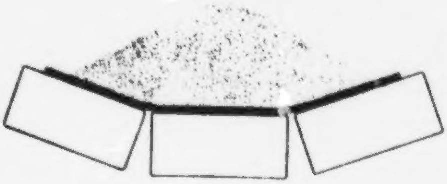


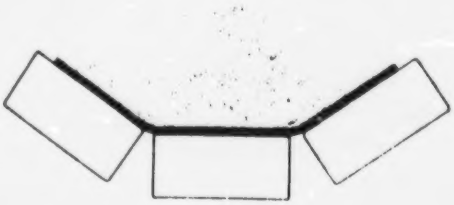
FIGURE VI-2 BELT FEEDER



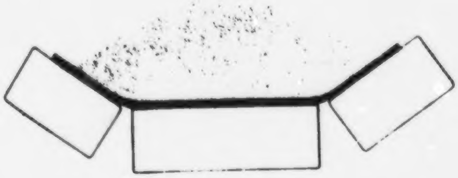
A. FLAT BELT ON FLAT BELT IDLERS.



B. TROUGHED BELT ON 20° IDLERS.

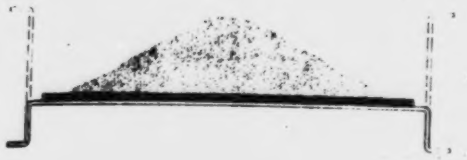


C. TROUGHED BELT ON 35° IDLERS.
IDLERS WITH ROLLS OF EQUAL LENGTH.

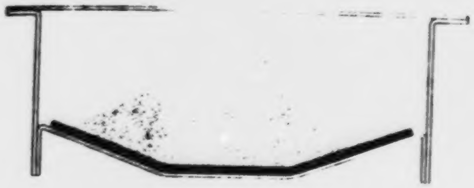


D. TROUGHED BELT ON 35° IDLERS.
IDLERS WITH ROLLS OF UNEQUAL LENGTH.

FIGURE VI-3 IDLER BELT FEEDER CROSS SECTIONS



A. FLAT BELT ON CONTINUOUS PLATE.



B. TROUGHED BELT ON CONTINUOUS PLATE.

FIGURE VI-4 SLIDER BELT FEEDER
CROSS SECTIONS

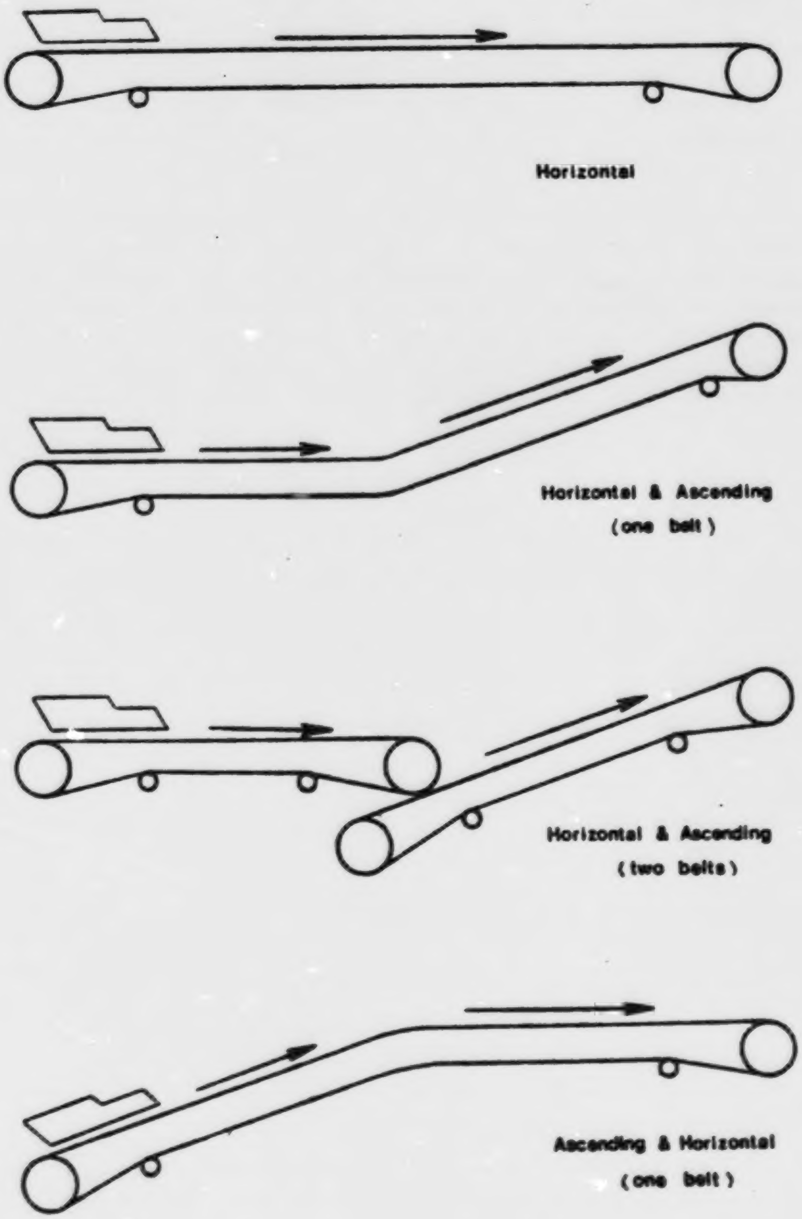

Horizontal
Horizontal & Ascending
(one belt)
Horizontal & Ascending
(two belts)
Ascending & Horizontal
(one belt)

FIGURE VI-5 BELT FEEDER ARRANGEMENTS

2. Performance Characteristics and Costs

Volumetric belt feeders perform conveying functions and do not meter or distribute material. Gravimetric belr feeders perform metering as well as conveying functions.

The capacities of belt feeders are dependent on belt width, speed and troughing arrangement. Table VI-2 shows typical belt capacities for wood residues for various belt widths and troughing at a belt speed of 15 meters per minute. Feeder capacities will vary proportionally at different belt speeds. The maximum speed allowable for belt feeders carrying wood residues is approximately 30 meters per minute.

TABLE VI-2

Belt Feeder Capacities* (t/h)

Belt Width \ Trough Angle	0°	20°	35°	40°
18	3.5	5.7	6.8	7.1
24	6.6	10.9	12.9	13.6
30	10.6	17.7	21.0	22.1
36	15.6	26.1	31.1	32.7
42	21.7	36.3	43.1	45.3

*Based on belt speed of 15 m/min (feeder capacities are proportional to belt speed) and a material density of 320 kg/m^3.

Power requirements of belt feeders are dependent upon many design characteristics of the feeder. Only a small amount of power is necessary to drive the belt once it has been accelerated to operating speed, usually between 0.1 to 0.3 kW total. However, drive motors must be sized so as to be able to start the belt under full loads. Proper sizing requires an extensive analysis based on feeder design and motor torque characteristics. A thorough discussion on power requirements and motor selection may be found in "Belt Conveyors for Bulk Materials" prepared by the Engineering Conference of the Conveyor Equipment Manufacturers Association (CEMA).

Belt feeders are suitable for non-sticky materials sized to minus 10 centimeters. Fine, light material such as sawdust and shavings can be conveyed using belt feeders, but care must be taken when choosing belt speeds to ensure material will not be blown off the belt. These feeders may be equipped with covers to minimize this problem and also problems with dust.

The cost of belt feeders are quite sensitive to the complexity of design. Simple, horizontal feeders requiring moderate support structures may cost as little as $150 per tonne per hour, whereas longer, complex feeders may cost as much as $400 per tonne per hour.

3. Guidelines for Proper Use

The best application for belt feeders is for the feeding of wood chips. Finer and lighter material can be fed using belt feeders, but at a cost of slower belt speeds and therefore less capacity. Damp and sticky material such as hog fuel may be fed by belts, but belt cleaners must be installed to prevent buildup of material on the belt. Belt cleaners add to capital and operating costs of the feed system and increase power requirements of the feeder. Belt feeders are not suitable for carrying abrasive material since it leads to excessive belt wear and short belt life.

Belt feeders used to feed residues may be orientated horizontally or at an incline. Belt feeders carrying wood residue at an incline must be held to a maximum slope of 15 degrees. Inclined feeders are more costly and require greater power than horizontal feeders.

4. Applications and Status of Technology

Belt feeders do not provide a seal and accordingly can not be used to directly feed pressurized systems. Their best application is with conventional conversion units in conjunction with multiple feed chutes which distribute the material along the full furnace area.

Belt feeders provide positive and accurate extraction from bins and when driven by variable speed motors have good speed and, hence, feedrate control. These feeders are of simple construction and exhibit clean operation and low power consumption. However, belt feeders require high design costs and cannot handle materials with a sticky or abrasive characteristic nor large pieces or slabs.

Generally, belt feeders are sound and reliable devices as long as care is taken to protect the belt from damage. Typical maintenance includes lubrication of terminal pulleys and idlers, and adjustment of belt tension and of the belt cleaners.

5. Manufacturers

Generally, any major materials-handling design company can provide belt feeders. A list of these companies would include:

FMC Corp.
Joy Manufacturing Co.
Stephens Adamson Division of Allis-Chalmers
Saddler Ltd.
Jeffrey Mfg Division of Dresser Industries Inc.
BIF
Iowa Manufacturing Company
Lamb Cargate Industries Ltd.
Merrick Scale Manufacturing Co.
Thayer Scale - Hyer Industries Ltd.

D. Feeder Chute

1. Design and Performance Characteristics

Feeder chutes are a common means of feeding furnaces and combustors and are usually an integral component of the reactor shell (Figure VI-6). The chuting is usually rectangular in cross-section, constructed from steel plate and can be built to any size to handle virtually any capacity. Often multiple feeder chute arrangements are employed along the wall of the wood conversion unit to ensure reasonable distribution of fuel across the whole reactor area.

Feeder chutes are the most elementary of feeders, relying simply on force of gravity to feed the wood conversion unit. Feeder chutes have low costs, and power requirements are nil.

Feeder chutes do not have any metering capabilities; however, given enough chute height and proper design of the chute discharge, reasonable distribution of material across the reactor base can be expected. Virually any material size can be handled by feeder chutes, as long as the chute cross-section is large enough. However, usually long pieces and slabs present problems with plugging and are not recommended for feeding with feeder chutes.

2. Applications and Guidelines for Proper Use

Feeder chutes are best applied on large conventional wood conversion units with sloping grate floors. It is important that feeder chutes are properly designed to ensure proper feeding and distribution and to prevent plugging of the chute. Feeder chutes must be adequately dimensioned so that the cross-section is large enough to handle the largest of material to pass through the chute and long enough to ensure adequate particle velocity so that proper distribution is achieved.

Feeder chutes should have as large a slope as possible and interior walls should be smooth with no protrusions into the chute. The chute cross-section should at least remain constant throughout its length, though a slight divergence is preferable, and should never be convergent since this will lead to problems with plugging.

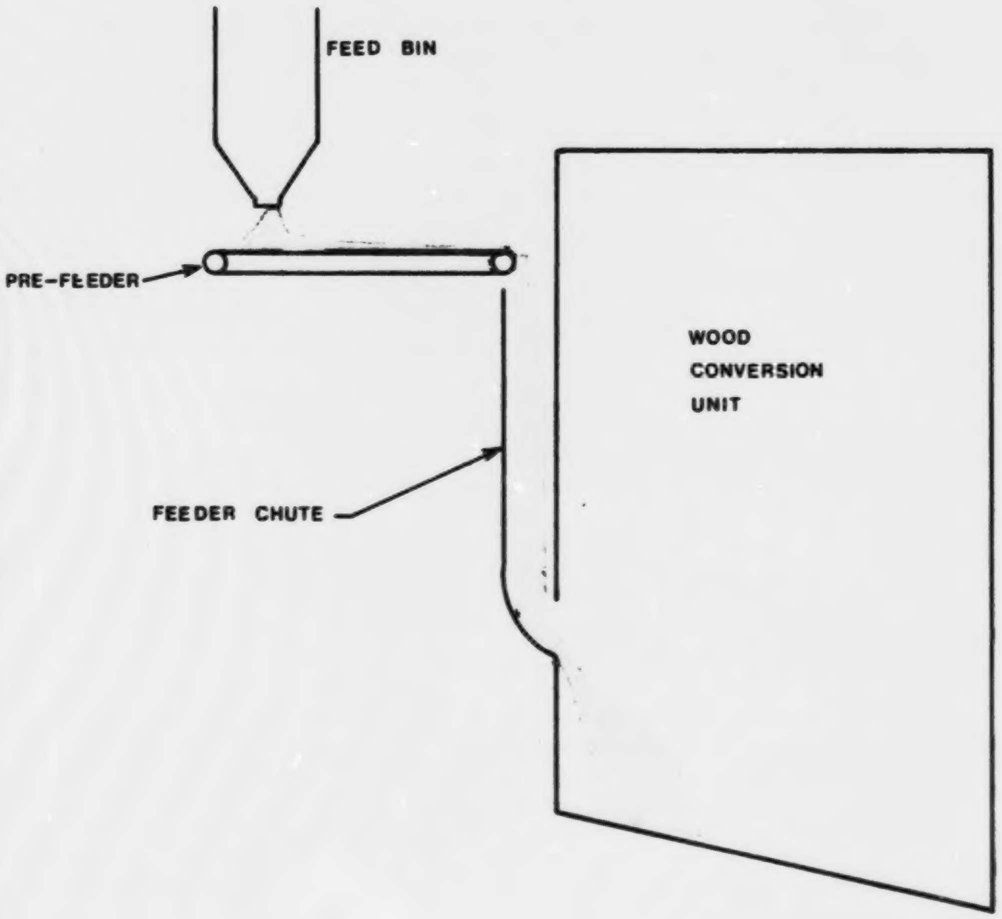

FEED BIN
PRE-FEEDER
WOOD CONVERSION UNIT
FEEDER CHUTE

FIGURE VI-6 FEEDER CHUTE

E. Flight Conveyor Feeder

1. Design and Operating Principle

Flight conveyor feeders consist of an arrangement of flights connected by a strand of chain operating on a plate or trough between terminal pulleys (Figure VI-7). The feeder is located beneath a bin opening where loading occurs and discharges at the end of the feeder or at intermediate points through slider gates in the base plate (Figure VI-8). Feed rates are controlled by conveyor speeds and bin opening size.

Generally, flights may be up to 100 centimeters wide by 30 centimeters high. To reduce wear of flights and the base plate, ultra high molecular weight polyethylene (UHMW) may be used to cover the base plate. The flights themselves may also be constructed of UHMW polyethylene, however, bending and breaking problems may occur with this design.

2. Performance Characteristics and Costs

Flight conveyor feeders do not meter material as they feed but can, with the employment of intermediate slide case and feed chutes, be used to distribute material to a certain extent. The capacity of these feeders depends on feeder speed, flight width and depth, and feeder slope. Table VI-3 shows typical capacities for wood residues for various flight dimensions at 30 meters per minute. Also shown in this table are acceptable material size for the various flight dimensions. For inclined flight conveyor feeders, capacities can be determined by multiplying by the factors for various slopes given in Table VI-4.

Theoretical requirements for flight conveyor feeders can be determined from the relationship:

$$P = \frac{(2W_c L F_c + W_m L F_m)\, V}{6{,}120}$$

where: P = power requirement (kW)
W_c = weight per meter of feeder element (kg)
W_m = weight of material carried per meter of feed (kg)
L = length of feeder (m)
F_c = friction coefficient of feeder element
F_m = friction coefficient of material
V = feeder speed (m/min)

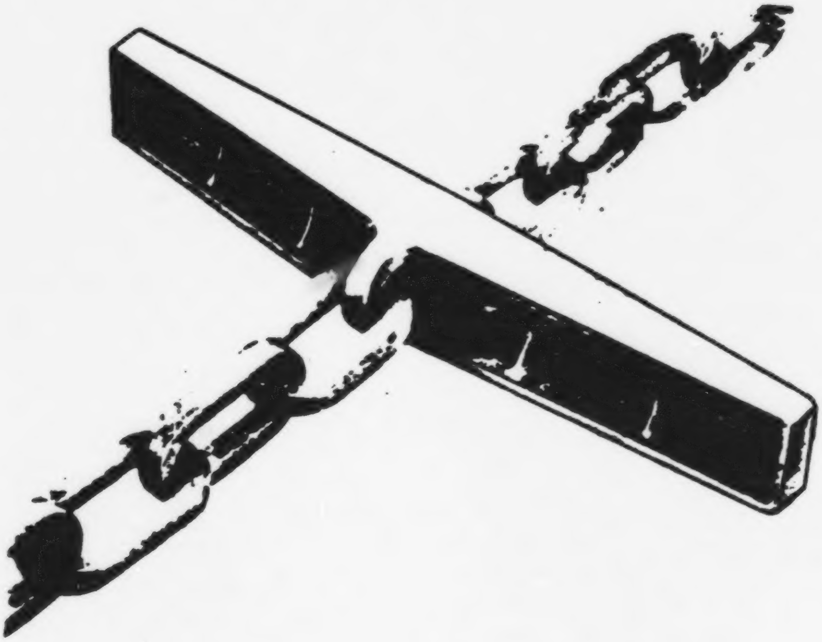
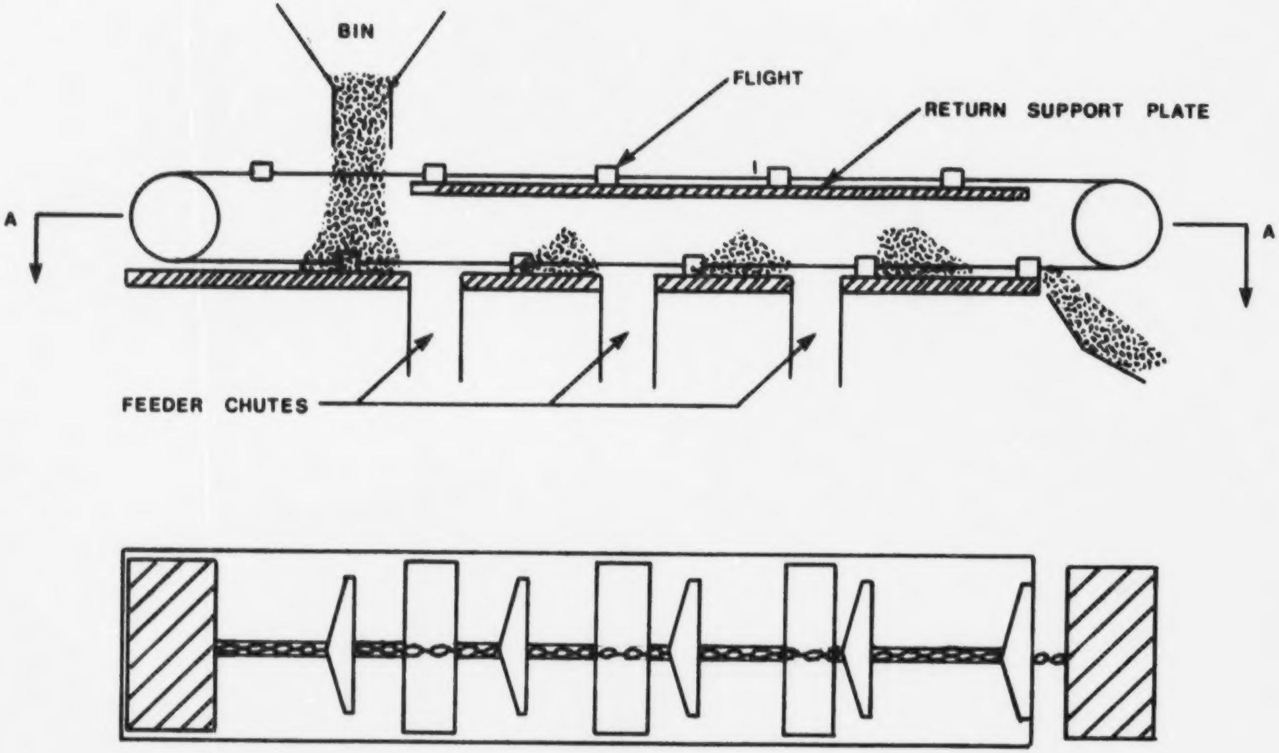


FIGURE VI-7 FLIGHT CONVEYOR


BIN
FLIGHT
RETURN SUPPORT PLATE
A
A
FEEDER CHUTES

SECTION A-A

FIGURE VI-8 FLIGHT CONVEYOR FEEDER ARRANGEMENT

TABLE VI-3

Flight Conveyor Feeder Capacity

FLIGHT WIDTH x DEPTH (cm)	VOL. OF MATERIAL PER CONVEYOR LENGTH (m^3/m)	FEEDRATE* AT 30 m/min (t/h)	PARTICLE SIZE (cm) NOT TO EXCEED 10% OF TOTAL	
			SINGLE STRAND	DOUBLE STRAND
30 x 15	.0372	21.8	9	10
38 x 15	.0455	26.5	11	13
45 x 15	.0520	30.5	13	15
60 x 20	.1078	63.1	--	25
75 x 25	.1486	87.1	--	35
90 x 30	.2230	130.6	--	40

*Based on material density of 320 kg/m^3. For conveyor speeds other than 30 m/min, capacity is proportional to speed.

TABLE VI-4

Inclined Flight Conveyor Feeder Capacity Factors

INCLINATION (degrees)	<20	20	25	30	35
FACTOR	1.0	0.9	0.8	0.7	0.6

Typically, the friction coefficient for flights travelling over a steel plate is 0.33 and that of wood residue on steel plate ranges from 0.30 to 0.45. Generally, the power requirement determined by the above equation is increased by 30 to 50 percent to take into account power losses due to bearing friction and reduction gearing and for starting or surge loads. Typically, power requirements for flight conveyor feeders are in the order of 0.1 kW per tonne per hour.

Costs for flight conveyor feeders are sensitive to length of feeder and feeder arrangement. Typically, capital costs of these feeders would range from $300 to $400 per tonne per hour capacity.

3. Applications and Guidelines for Proper Use

Flight conveyor feeders are most applicable to conventional wood conversion systems such as wood-fired boilers. They are commonly used in conjunction with intermediate and discharge feeder chutes to aid in distribution of material throughout the reactor.

Flight conveyor feeders are suitable for feeding all wood residues that are not excessively long or stringy. The material may be wet or dry and should preferably be free of grit or other abrasive material.

4. Status of Technology and Use

The major advantages of the flight conveyor feeder are its high capacity, versatility and reasonable distribution characteristics. However, this feeder is vulnerable to loosing flights into the system and to chain breakage without warning, leading to long down time.

Typical maintenance of the flight conveyor includes routine lubrication, ensuring proper chain tensioning, wear plate replacement and chain replacement. With the ultra high molecular weight polyethylene as a cover on the base plate, its service lifetime may be dramatically increased.

5. Manufacturers

In general, all major materials handling design and manufacturing companies can supply flight conveyor feeders. A list of these would include:

Stephens Adamson Division of Allis-Chalmers
FMC Corp.
S.W. Hooper and Co. Ltd.
Jeffrey Mfg Division of Dresser Industries Inc.
Sprout Waldron Division of Koopers Company Inc.
C.E. Bauer

F. Gate Feeder

1. Operating Principle and Performance Characteristics

A gate feeder consists of a sliding plate located in a chute or bin bottom. The gate may be manually or automatically moved in or out of the chute or bin thereby regulating the size of the opening through which the material passes. Control of the feedrate is probably the least effective of all volumetric feeders. In addition to the size of the opening, the feedrate is a function of flowability (particle size and shape) of the residues and the weight of residues above the gate.

Gate feeders are designed and built to handle virtually any capacity of material. Like feeder chutes, cost of these feeders are minimal and power requirements nil. Gate feeders are best used with small (minus 5 cm), non-sticky, free-flowing material having a vertical flow path. Generally, these feeders lose control of flowrate and cause bridging of material in the feed chute to the gate when the gate is operated partially open. Avoidance of this problem requires use of a bin agitator of some kind.

2. Applications and Guidelines for Proper Use

Gate feeders are commonly used as prefeeders, such as in the loading chute of a belt feeder, and are never used alone to directly feed wood conversion units. Because of their poor feed control when partially opened, gate feeders are best used for on/off applications when equipment isolation is required for maintenance.

When handling dry, fine material, gate feeders may be used in sloping chutes although this configuration is not desirable.

Gate feeders are usually supplied with the bins or are shop-made by mill personnel. These feeders should only be used on feed bins in conjunction with a type of feed conveyor or bin activator that will ensure flow of materials through the gate.

G. Linear Pocket Feeder

1. Design and Operating Principle

The linear pocket feeder (LPF) is currently being developed by Foster-Miller Associates, Inc. under sponsorship of the United States Department of Energy. A prototype LPF has been designed specifically for the purpose of feeding pulverized coal to a pressurized fluid-bed combustor or gasifier, although in general, any solid can be fed using this feeder.

The LPF system (Figure VI-9) can essentially be broken down into five different sections; the loading section, the sealing section, the discharge section, the gas-water transfer section, and the return section. The LPF is basically a tubular conveyor in which a series of sealing pistons are connected to form pockets. Material from the hopper is loaded into the feeder in the loading section and is pulled through the sealing section where the radial clearance between the piston assemblies and the tube is approximately 0.025 mm. The solid is dumped into the high-pressure reactor in the discharge section where high-pressure gas enters the pockets in exchange for the solid material. This gas is displaced and returned to the reactor by high-pressure water in the gas-water transfer section. Finally, the piston assemblies are returned to the loading section. Along the path in the return section, water is removed from the pistons by high-velocity air.

The piston assemblies form a basic conveyor chain and are composed of pistons, wear rings and connecting links. The chain has a single degree of freedom about the vertical axis and the wear ring is so designed as to accomplish any "bite-off" encountered at the feed section. As the solid drops between the moving pistons, there exists the possibility of jamming the material between the tube and the pistons. To overcome this problem, a spiral taper design is used for the inlet tube.

At the discharge section, high-pressure purge gas from the gas-water transfer section is used to assist in unloading the feeder. The gas-water transfer station is a pressure vessel filled with high-pressure water through which the conveyor chain moves. The gas displaced by the water is passed through a drying system and back to the reactor. Both the discharge section and gas-water transfer station are designed in accordance with the ASME unfired pressure vessel code.

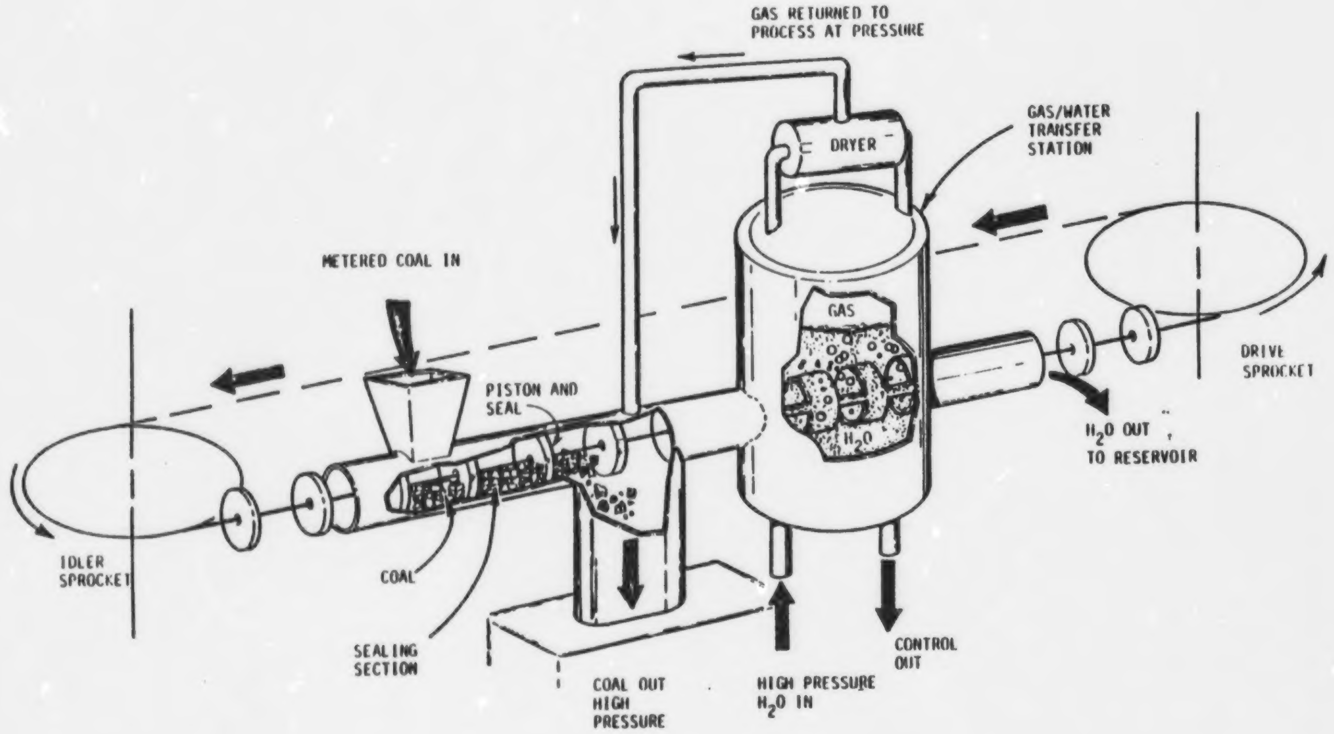

GAS RETURNED TO PROCESS AT PRESSURE
DRYER
GAS/WATER TRANSFER STATION
METERED COAL IN
GAS
PISTON AND SEAL
H_2O
DRIVE SPROCKET
H_2O OUT TO RESERVOIR
IDLER SPROCKET
COAL
SEALING SECTION
COAL OUT HIGH PRESSURE
HIGH PRESSURE H_2O IN
CONTROL OUT

FIGURE VI-9 FOSTER-MILLER LINEAR POCKET FEEDER

2. Performance Characteristics and Costs

The linear pocket feeder does not perform metering or distributing functions, but only conveys material from the inlet hopper to the reactor. Solids are metered to the hopper by some metering device which is used to control flowrate. The drive system for the feeder includes motor, controls, gear box and chain drive. The motor has variable speed capabilities allowing conveyor speeds to range from 0 to 1 meter per second.

The prototype LPF designed by Foster-Miller was tested using coal sized to minus 20 mm and a maximum feedrate of 4.5 t/h. This prototype was tested with a reactor pressure of 3,450 kPa, however, its operation was also projected up to a 10,450 kPa reactor pressure. Performance parameters of the prototype LPF testing are shwon in Table VI-5.

Conceptual designs have been developed by Foster-Miller Associates for scaling the LPF up to feedrates of 225 t/h of coal. Table VI-6 shows projected power requirements and physical dimensions of these designs compared to the prototype. the larger linear pocket feeders will of course be able to handle a larger size of material. For example, the 26 cm tube diameter LPF can feed coal up to 4.4 cm in size.

At this stage of its development, costing for the LPF is tentative at best. The projected installed cost for a linear pocket feeder with a capacity of 45 t/h should range between $1 million and $1.3 million (1982), depending on reactor pressure.

3. Applications and Guidelines for Proper Use

The linear pocket feeder has been successfully demonstrated as being a suitable feeder for gasifiers and pressurized fluid-bed combustors. Although the prototype feeder has only been tested with coal, it would appear that it should be suitable for feeding wood residue which has been adequately reduced in size. Problems would be encountered with long, sticky or stringy residues and these should not be fed with the LPF.

Since the LPF does not meter material adequately, a suitable metering device is required to feed the inlet hopper. This may be a standard, off-the-shelf device such as a weight belt or a screw. The distribution characteristics of the LPF is suitable for top feeding of gasifiers and combustors.

TABLE VI-5

Linear Pocket Feeder Prototype Performance

Parameter	Prototype Performance
Tube Diameter, cm	8.75
Overall Length, m	6
Coal Size	200 mesh to 20 mm
Feedrate, t/h	4.5
Reactor Pressure, kPa	3,450
Gas Leakage (@ 3,450 kPa, 4.5 t/h, 0.67 m/s) m^3/min, 15°C, 101 kPa	0.17
Specific Leakage (@ 3,450 kPa, 0.67 m/s) m^3/t, 15°C, 101 kPa	2.3
Total System Power Requirements, kW	35
Specific Power, kWh/t	7.8
Line Pull, kg	180 to 270
Line Pull Power Requirement, kW	2 to 3

TABLE VI-6

Power Required and Physical Dimensions of Linear Pocket Feeders

Feedrate t/h	Physical Dimensions		Power Requirements, kW		
	Tube ID, cm	Length, m	@ 3,450 kPa	@ 6,890 kPa	@ 10,450 kPa
*4.5	8.75	6.1	35	70	105
45	26.25	12.2	169	337	506
115	40.00	16.8	421	843	1,264
225	55.00	24.4	843	1,686	2,529

*Prototype LPF tested parameters

The high-pressure water used to displace the gases must be chemically inhibited and the system requires flow and level controls. This water is supplied by a closed loop system which uses filters to remove fines from the water.

4. Status of Technology and Use

The prototype of the linear pocket feeder developed by Foster Miller Associates Inc. has accumulated over 500 operating hours on coal and no critical reliability problems have been encountered. Although no testing of this feeder with wood residue has been performed, few changes to the system would be necessary for the handling of this material.

One area of concern of the LPF handling wood residue is that of material bridging due to flow interference by the connecting links. The tube diameter must be sized such that the effect of this link would not hinder the flow of wood residue at the discharge point of the feeder.

The LPF offers several advantages over other feeders for similar applications. The use of redundant seals in the sealing section minimizes gas leakage and offers "backup" for worn or damaged seals. In cases of chain breakage during operation, the chain assembly is mechanically restrained to seal the tubes and prevent venting of high-pressure gas. Also, the system is pressure balanced, the forces of gas pressure on the chain assembly are equal and opposite. Thus, the drive system must only overcome forces due to friction between the tube and both the seals and conveyed material.

One major improvement of the LPF is deemed necessary prior to its commercialization. Because of the small diametrical clearance between the piston and tube required to provide an adequate seal, little wear of the piston perimeter can be tolerated. Material selection for the tube interior and the piston wear ring must be optimized to ensure a suitable life of the seal.

In addition to this problem, other disadvantages of the LPF include the necessity of handling a volume of chemically-treated, high-pressure water; high capital cost and the large space required.

H. Lock Hopper Feeders

1. Design and Operating Principle

A lock hopper in its simplest arrangement is a small bin with gas-tight valves on its inlet and outlet that is capable of withstanding internal pressures equal to the pressure when discharging. The lock hopper must have a suitable feed hopper to direct material in through the top valve and a suitable feed chute to direct material from the bottom valve to a reactor. Metering equipment may be used to control the supply to the feed hopper, or the rate of discharge from the lock hopper, or a combination of both.

In general, the operating sequence of a lock hopper is as follows:

- input feed material drops from the supply hopper through the open inlet valve to the primary lock hopper with the outlet valve closed;
- the inlet valve closes, and the lock hopper is pressurized to the process system pressure;
- the lock hopper outlet valve opens and material flows by gravity to a meter hopper which is at or near process system pressure;
- feed material is metered to various devices which inject the material to process;
- while material is being metered and injected to process the lock hopper outlet valve closes and the lock hopper is de-pressurized to atmospheric pressure by venting;
- the lock hopper inlet valve is opened for intake of the next batch of feed material.

A basic lock hopper feeder system is illustrated in figure VI-10. Several variations of a basic lock hopper are possible, depending on the design of the discharge. These designs may be grouped as follows:

- Gravity discharge and injection;
- Pneumatic metering and injection;
- Screw metering and injection.

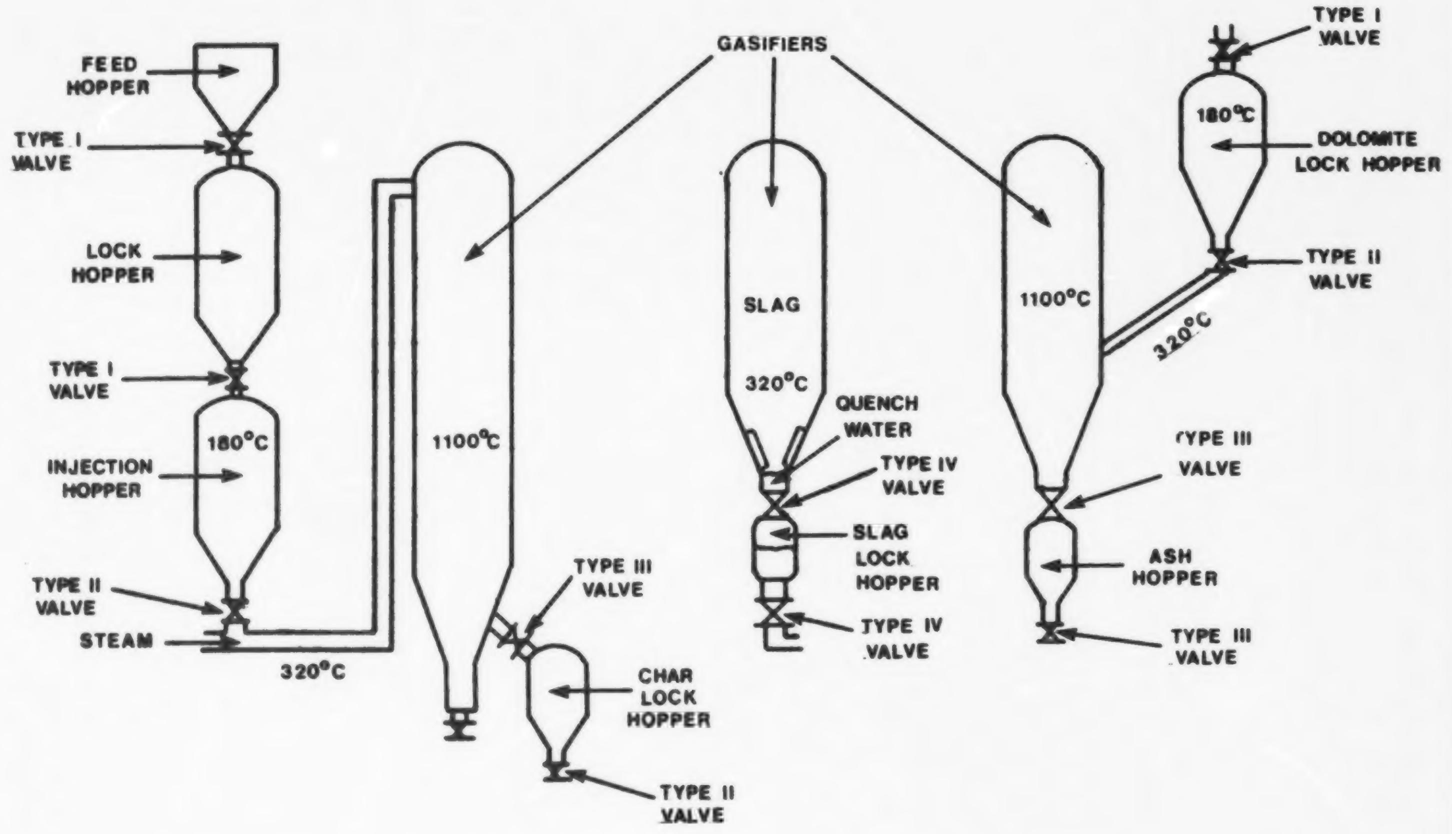

GASIFIERS
FEED HOPPER
TYPE I VALVE
LOCK HOPPER
TYPE I VALVE
180°C
INJECTION HOPPER
TYPE II VALVE
STEAM
320°C
1100°C
TYPE III VALVE
CHAR LOCK HOPPER
TYPE II VALVE
SLAG
320°C
QUENCH WATER
TYPE IV VALVE
SLAG LOCK HOPPER
TYPE IV VALVE
1100°C
320°C
TYPE III VALVE
ASH HOPPER
TYPE III VALVE
TYPE I VALVE
180°C
DOLOMITE LOCK HOPPER
TYPE II VALVE

FIGURE VI-10 LOCK HOPPER APPLICATIONS

It must be understood that the above systems are selected only to illustrate some available alternatives. Other equivalent, satisfactory systems are available and are included in the list of manufacturers forming part of this report.

a) Gravity Discharge

This type of feeder is represented by the Gatx-Fuller Gate Lock shown in Figure VI-11. The Riley lock hopper shown in Figure VI-12 is comparable to the Gatx-Fuller Gate Lock. Another design is the Lurgi lock hopper for coal gasifiers shown in Figure VI-13.

The Fuller Gate Lock system uses air tight flapper valves on the inlet and outlet of the lock hopper, as well as the bottom of the supply hopper. The supply hopper valves are operated by mechanical linkages from the airtight lock hopper valves. The two airtight lock hopper valves are alternately and synchronously opened and closed in a set timing sequence. The system is commercially available for handling abrasive, lumpy, or deformable materials.

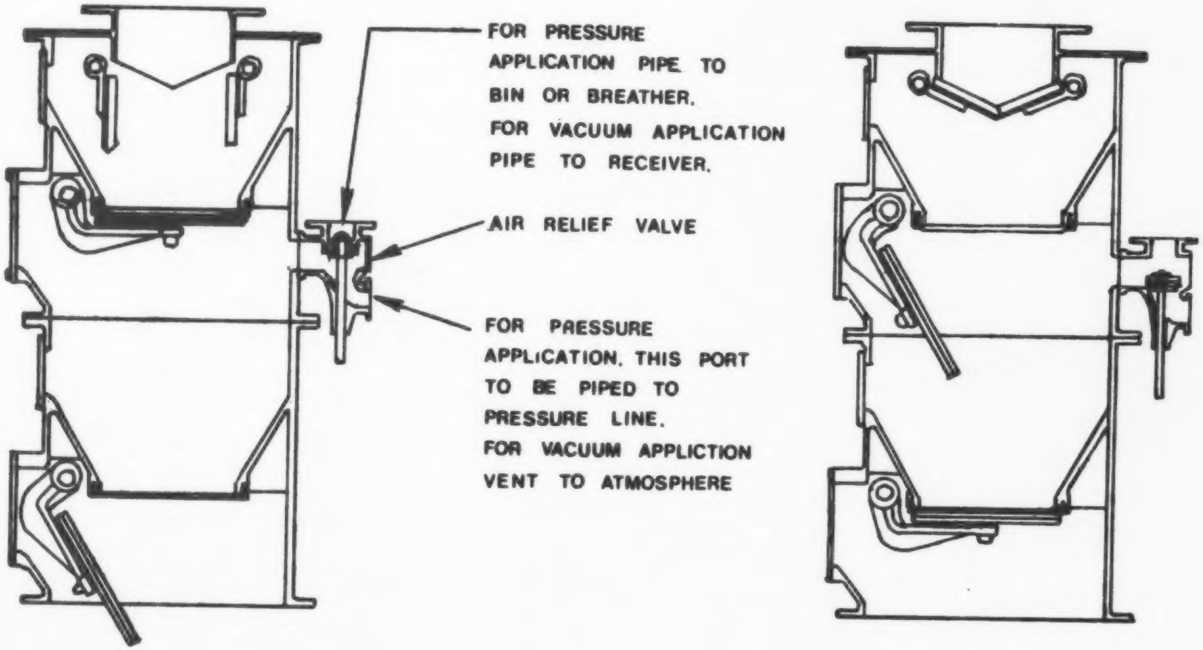
The Riley lock/purge hopper used with the Riley Coal Gasifier is comparable to the GATX-Fuller Gate Lock but uses semi-ball type flow control valves to prevent gas migration from process to the coal bunker. During the purge cycle a steam eductor evacuates gas from the lock hopper for discharge downstream, to gas piping. A chute on the outlet of the lock hopper provides continuous feed to process through a rotory coal feeder during the refill cycle.

The Lurgi lock feeder for pressurized coal gasifiers uses conical poppet type valves on the inlet and outlet of the lock hopper feeder. The feeder is commercially available and widely used to feed coal. The conical closure valve is installed so that the working pressure forces the valve closed, and thus, assists in achieving a seal.

b) Pneumatic Metering and Injection

This design is manufactured by Macawber Engineering Inc. and Petro Carb Inc.

The Macawber system shown in Figure VI-14 utilizes swing dome valves at the inlet and outlet of the lock hopper. Dry free-flowing material sized to be less than


FOR PRESSURE APPLICATION PIPE TO BIN OR BREATHER.
FOR VACUUM APPLICATION PIPE TO RECEIVER.
AIR RELIEF VALVE
FOR PRESSURE APPLICATION. THIS PORT TO BE PIPED TO PRESSURE LINE.
FOR VACUUM APPLICTION VENT TO ATMOSPHERE

A. CHARGE UPPER CHAMBER -
DISCHARGE LOWER CHAMBER

B. CHARGE LOWER CHAMBER

FIGURE VI-11 FULLER STANDARD GATELOCK

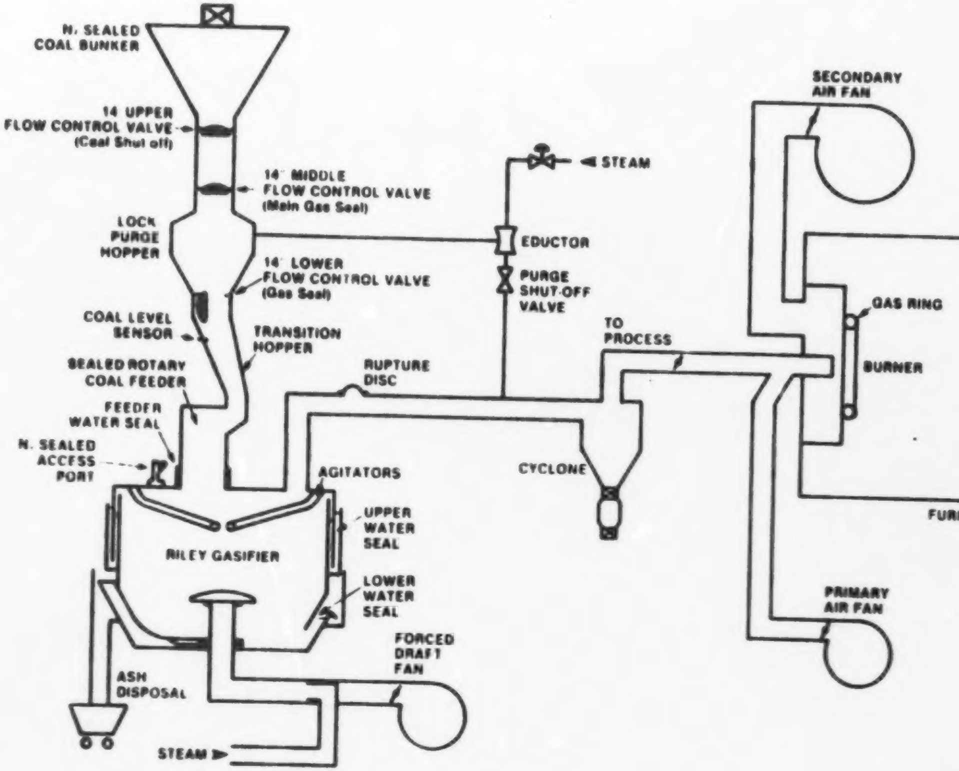

N. SEALED COAL BUNKER
14 UPPER FLOW CONTROL VALVE (Coal Shut off)
14" MIDDLE FLOW CONTROL VALVE (Main Gas Seal)
LOCK PURGE HOPPER
14" LOWER FLOW CONTROL VALVE (Gas Seal)
COAL LEVEL SENSOR
TRANSITION HOPPER
SEALED ROTARY COAL FEEDER
FEEDER WATER SEAL
N. SEALED ACCESS PORT
RUPTURE DISC
AGITATORS
UPPER WATER SEAL
RILEY GASIFIER
LOWER WATER SEAL
FORCED DRAFT FAN
ASH DISPOSAL
STEAM
STEAM
EDUCTOR
PURGE SHUT-OFF VALVE
TO PROCESS
CYCLONE
SECONDARY AIR FAN
GAS RING
BURNER
FURNACE
PRIMARY AIR FAN

FIGURE VI-12 RILEY GASIFIER AND LOCK HOPPER FEEDER

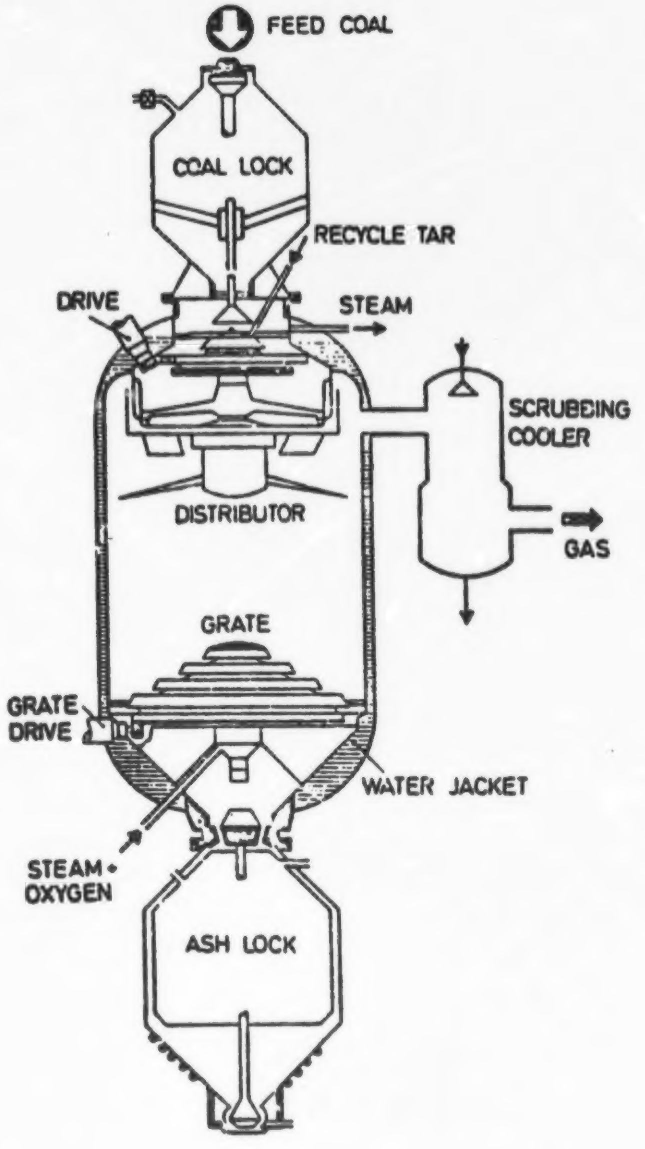

FEED COAL
COAL LOCK
RECYCLE TAR
DRIVE
STEAM
SCRUBBING
COOLER
DISTRIBUTOR
GAS
GRATE
GRATE
DRIVE
WATER JACKET
STEAM +
OXYGEN
ASH LOCK

FIGURE VI-13 LURGI PRESSURE GASIFIER AND LOCK HOPPER FEEDER

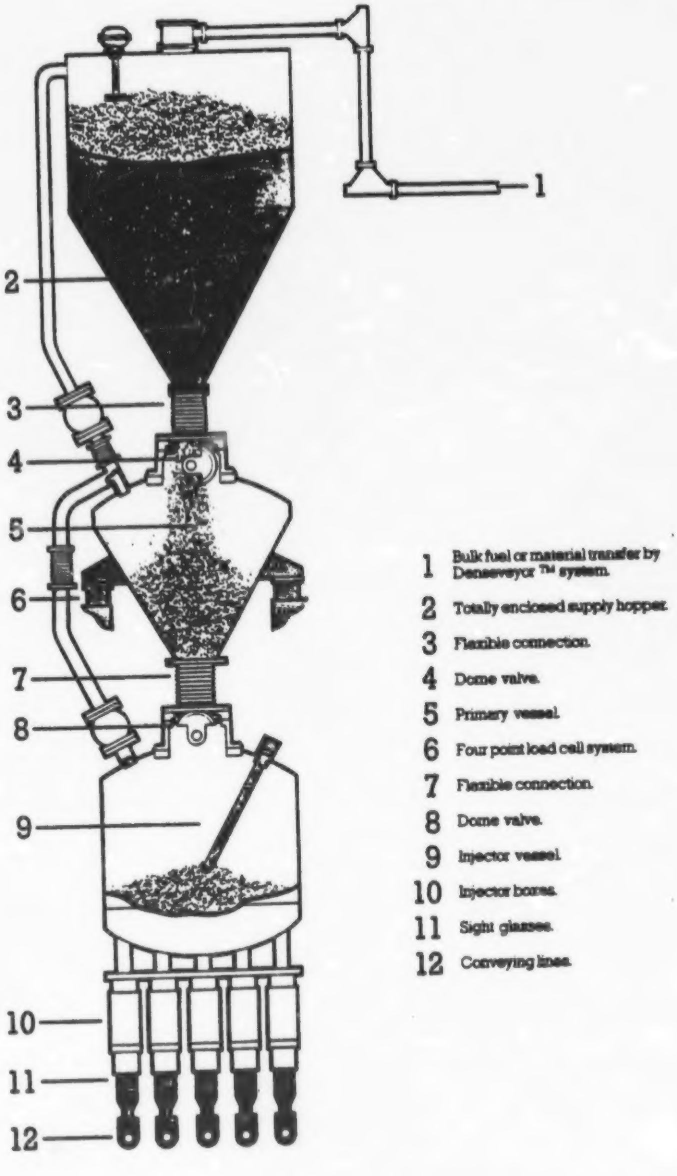

1
2
3
4
5
6
7
8
9
10
11
12
1 Bulk fuel or material transfer by Denseveyor ™ system.
2 Totally enclosed supply hopper.
3 Flexible connection.
4 Dome valve.
5 Primary vessel.
6 Four point load cell system.
7 Flexible connection.
8 Dome valve.
9 Injector vessel.
10 Injector bores.
11 Sight glasses.
12 Conveying lines.

FIGURE VI-14 MACAWBER LOCK HOPPER FEEDER

3 mm is metered to process by a transport gas and using a variable orifice flow control. The system is commercially available for feeding coke breeze to foundry furnaces, coal to combustors, and chemicals and foodstuffs to various processes.

The Petrocarb system utilizes process gas to pressurize the storage lock hopper and metering hopper. Compressed air is used to continuously inject coal from the pressurized metering hopper to process. Systems are custom designed for specific applications.

c) Screw Metering and Injection

This design is represented by the Miles Biomass Feeder show in Figure VI-15. The system divides feeding into three separately controllable operations, namely pressure change variable rate metering, and injection. Biomass is fed to the lock hopper which is pressurized to allow gravity transfer to the meter bin. Multiple metering screws inside the meter bin feed biomass to an injection screw which feeds it to the pressurized system. The biomass may be injected directly into a pressurized reactor. In existing applications with pressurized gasifiers, the biomass is injected very rapidly into reactor temperatures of about 400°C avoiding pre-ignition. Variable penetration into a fuel bed is also possible. This feeder system is usually designed to specific application requirements.

2. Performance Characteristics and Costs

Performance characteristic of lock hopper feeders are summarized in Table VI-7 using the following classifications:

- Gravity Discharge
- Pneumatic Metering and injection
- Screw Metering and Injection

Data on power requirements of the various types and sizes of lock hoppers are not readily available. One literature reference indicates 8.2 kW per tonne per hour of coal for a Lurgi feeder discharging to a reactor at 3,103 kPa. The power requirement of a non-pressurized Miles Biomass Feeder is about 5 hp for the sizes of units made to date (0.02-2 t/h). For

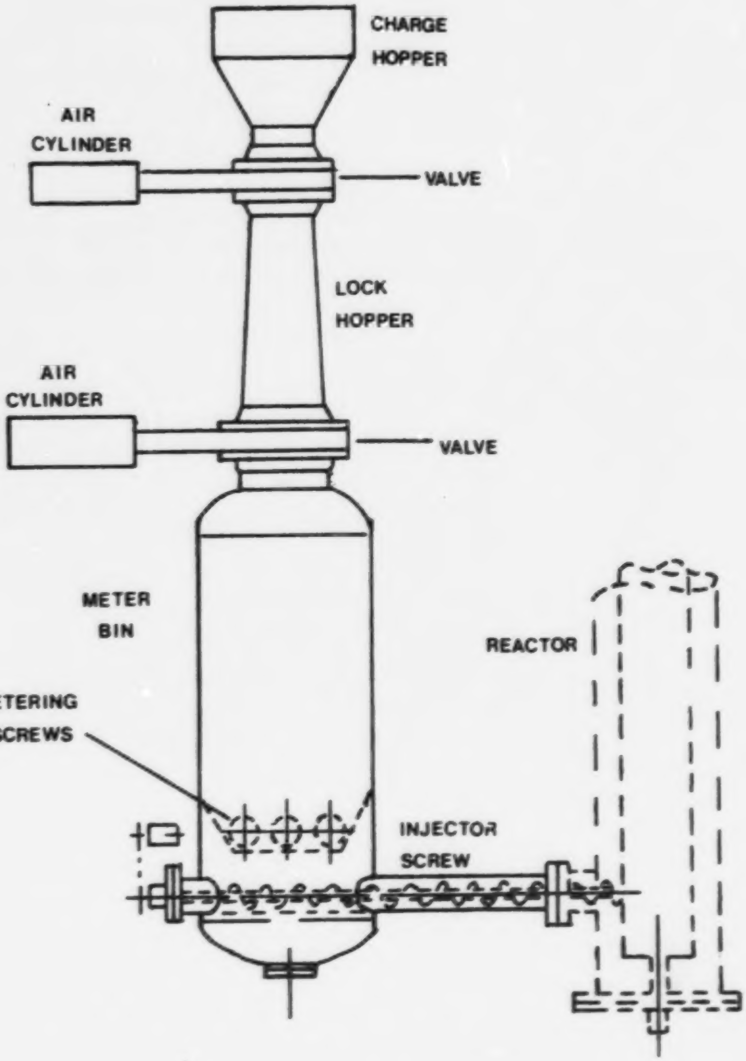

CHARGE
HOPPER
AIR
CYLINDER
VALVE
LOCK
HOPPER
AIR
CYLINDER
VALVE
METER
BIN
REACTOR
METERING
SCREWS
INJECTOR
SCREW

FIGURE VI-15 MILES BIOMASS FEEDER

TABLE VI-7

Characteristics of Lock Hopper Feeders

Type of Discharge: Manufacturer	Feed Material	Feed Size mm	Capacity Range t/h	Differential Pressure kPa	Status and Comments
GRAVITY:					
Gatx-Fuller Ltd.	Lime Sand Alum	not critical	4.9 9.25	103	-to 121°C with urethane seals -to 204°C with vitom seals -commercial
Riley Stoker Corporation	Coal	to 51 X 25	5.45	not known -estimate about 103	-demonstrated on 2.1 m diameter gasifier
Lurgi	Coal (dry)	all sizes to 100	to 70	3,185 typical 8,494 max.	-established technology
PNEUMATIC:					
Macawber Engineering	Coke Breeze Coal Chemicals (dry)	below 3	0.06-12	69	-established technology -accuracy ± 2%
Petrocarb, Inc.	Peat Coal Ore Dolomite	0.075-3.17	to 55	to 4,137	-established technology
SCREW:					
Thomas R. Miles Consulting Engineers (designer only)	Wood Chips Wood Pellets	less than 50	0.02-2.0	to 2,068 (6,895 in design)	-used on demonstration scale gasifier -meters -accuracy 2% -4 units operating -2 units in design

pressurized systems, the power required by the compressor to pressurize the lock hopper must be added to the value noted above.

Very little cost data is available on lock hoppers. The Gatx-Fuller Gatelock costs about $17,800 (U.S. 1982). A Lurgi lock hopper is about $14,800 (U.S. 1979) per tonne of capacity. The cost of Miles Biomass feeders installed recently for laboratory gasifiers have been as follows:

Feedrate (t/h)	Feed Pressure (kPa)	Cost (U.S.$)	Cost Includes
0.5	1,034	60,000	not installed with controls
1.0	2,067	150,000	complete installed
2.0	2,067	200,000	complete installed

3. Guidelines for Proper Use

Lock hoppers have been used for many years for feeding ores, coke breeze, coal etc. in foundry and metallurgical industries. In recent years this device has been finding increasing use in feeding coal to pressurized gasifiers. Recently lock hoppers have been applied to feeding biomass such as wood chips and wood pellets to biomass gasifiers.

The charging hopper can be loaded on a batch basis or by a continuous feeder. In most cases the charge hopper load is fed to the lock hopper on a batch basis controlled by a timer or level controller. The lock hopper load is also tranferred to the meter hopper on a batch basis. The feed material is then metered out of the meter bin by some injection or feeder device to the pressurized process. The purpose of the lock hopper system is to maintain control over any gases (sometimes toxic) that may leak from a pressurized process and to allow reasonable conventional feeders to function within a pressurized environment.

The performance of lock hoppers is quite sensitive to feed preparation. Sizing and control of moisture content for the feed that is needed depends largely on the process and the injection system used.

The advantages of lock hopper systems are:

- it is a simple basic design and a proven system for feeding coal and other bulk materials into high pressure reactors
- it can accept a wide range of particle sizes, size being limited only by conveying equipment and process.
- it can feed solid flowable material into high pressure systems without mechanically compacting the feed materials.

The disadvantages of lock hopper systems are:

- there is some loss of energy by venting pressurized lock hoppers. This can be decreased by using double parallel lock designs which increases through-put but, increase capital cost.
- the inflow must be stopped periodically in order to shut the upper valves without jamming.
- the charge hopper cannot be used under a head of inflow material unless a flow interrupter is used.
- since the inflow material is received in batches a metering device feeding out of the lock hopper is preferred in order to provide near continuous flow to process.
- lock valve preformance and reliability has been poor.
- For batch feeding a pile-height sensor is required to control the cycle time of the feeder. Pile-height sensors exposed to tar-laden gases have experienced problems with tar deposition and loss of reliability.
- The control system must be modestly complex to ensure proper timing of valve movements, pressurization and depressurization, and feedrate control.

Some valves fail to operate and tend to leak process gas. Tars leaking back from the gasification process aggravate valve malfunction unless steam purges or mechanical scrapers are used to remove tar that often builds up on the valve exposed to tar-laden gases because it is at emperature below the condensation point of these tars. This problem is most sever when restarting the unit after it has been allowed to cool.

4. Applications

Lock hopper systems are used to contain and control backflow gas emmissions from pressurized conversion systems. While the use of lock hoppers implies pressurized systems, it is instructive to discuss them as low pressure systems and high pressure systems classified as follows:

Low Pressure Feeders

- Gatx-Fuller Gate Lock
- Riley gravity chute
- Macawber pneumater

High Pressure Feeders

- Lurgi Coal Lock
- Petrocarb Pneumatic
- Miles Biomass

a) Low Pressure Feeders

i) Gatx-Fuller Gate Lock

The Gatx-Fuller Gate Lock requires a compressed air supply. Material flow to the inlet must be at a controlled rate from a screw feeder or other device not to exceed the maximum capacity of the gate lock system. At no time should the vent be used as a feeder under a head of material. The gate lock itself does not come supplied with a receiver such as a meter bin or feeder for injection to process. It can feed material from one atmosphere to another such as atmospheric pressure into a pressurized system or vacuum system. It could batch feed biomass by gravity to a combustor or low-pressure gasifier or pyrolyzer.

ii) Riley Lock Hopper

The Riley Lock Hopper provides coal feed to a chute which continuously supplies a rotary feeder inside the pressurized system. It has been used successfully feeding a demonstration scale rotating-bed coal gasifier.

iii) Macawber Pneumatic Feeder

The Macawber Pneumatic Feeders can provide accurate feeding of free-flowing, sized material to processes. Since fuel particles are suspended in air for injection, these systems could feed suspension burners.

b) High Pressure Systems

i) Lurgi Coal Lock

The Lurgi Coal Lock feeder has been widely used for high-pressure coal gasifiers and is expected to be satisfactory for similar duty feeding biomass.

ii) Petrocarb Pneumatic Feeder

The Petrocarb Pneumatic Feeder can accurately feed free-flowing, sized material to pressurized conversion systems. Since particles are suspended in air for injection, the system could feed pressurized chamber type combustors and suspension burners.

iii) Miles Biomass Feeder

The Miles Biomass Feeder can accurately meter sized biomass such as wood chips or smaller residues to pressurized conversion systems. A low-density (not compressed) plug of biomass can be injected with varying penetration directly into beds operating at temperatures of about 400°C. This system could feed fluid-bed combustors, fixed-bed or fluid-bed gasifiers and pyrolyzers. The unit could be used equally well for over-bed feeding.

5. Status of Technology and Use

Lock Hoppers have been used for many years to feed ores and metallurgical reagents in the foundry and metallurgical industries. They have also been used in the last 20 years or so to feed coal gasifiers. Only in very recent years have they been applied to biomass such as wood chips, etc.

The low-pressure feeders supplied by companies identified in this study have not been used for biomass such as wood residues as far as is known. Imbert and Duvant have both used simple lock hopper systems for feeding coarse residues to their gasifiers.

The high-pressure feeders noted above, except the Miles Biomass Feeder, have not been used for biomass. This design shows considerable promise because it can accurately meter an uncompressed (or only slightly compressed) plug of wood chips or other sized biomass to a pressurized high-temperature process. Problems that need attention are control of tars flowing from the conversion system back to the lock hopper and any malfunction of lock hopper valves resulting from tar build-up and leakage due to wood particle build-up.

6. Manufacturers

Some lock hopper systems are available complete from manufacturers while others are designed to suite the conversion system with which they are used. The latter situation is most common for wood and coal lock hopper feeders. The manufacturers and designers surveyed in this study were:

Duvant
Gatx-Fuller Ltd.
Imbert Energietechnik
Lurgi
Macawber Engineering Inc.
Petrocarb Inc.
Riley Stoker Corp.
T.R. Miles Consulting Design Engineers

I. Pneumatic Feeder

1. Design and Operating Principle

Pneumatic feeders consist of four basic components: a blower, a rotory feeder, a pipeline and a cyclone discharge (Figure VI-16). The air blower provides a stream of pressurized air (up to 34 or 41 kPa [gauge]) into which material is fed by a rotary feeder. This air-solids mixture is conveyed by the piping to the cyclone where it is separated and the solids are discharged through the bottom of the cyclone to the reactor.

The design of a pneumatic conveying system is still more an art than a science. Published "design procedures" for pneumatic conveying systems are actually energy analyses that purport to account for all of the losses in a system. They require information regarding air flow and conveying velocity that can only be obtained from existing installations or pilot plant tests. The effects of the material characterstics on the selection of equipment is shown in Table VI-8.

The type of air mover required by the systems is determined by the airflow and pressure required to entrain the specific material. Two types of air movers are commonly used, the positive displacement blower and the centrifugal fan. The positive displacement blower is preferred since it can develop high pressure to move material in a plugged line. The characteristics of a centrifugal fan are such that the volume drops rapidly (and thus the velocity) as the pressure increases. Overall system pressure drop is, therefore, extremely important.

Feedrates of pneumatic feeders are controled by the blower pressure, pipe diameter and by the feedrate of the rotary feeder. Material may either be fed directly into the conversion unit, or into a surge bin which then discharges into the reactor.

2. Performance Characteristics and Costs

Pneumatic feeders are capable of performing metering, conveying and distributing functions. Capacities of pneumatic feeders may range up to 250 tonnes per hour with travel distances of over 1,000 meters. Power requirements of pneumatic feeders are very high in comparison to other types of feeders. These requirements are dependent on feeder capacity and distance of travel and are shown in Table VI-17.

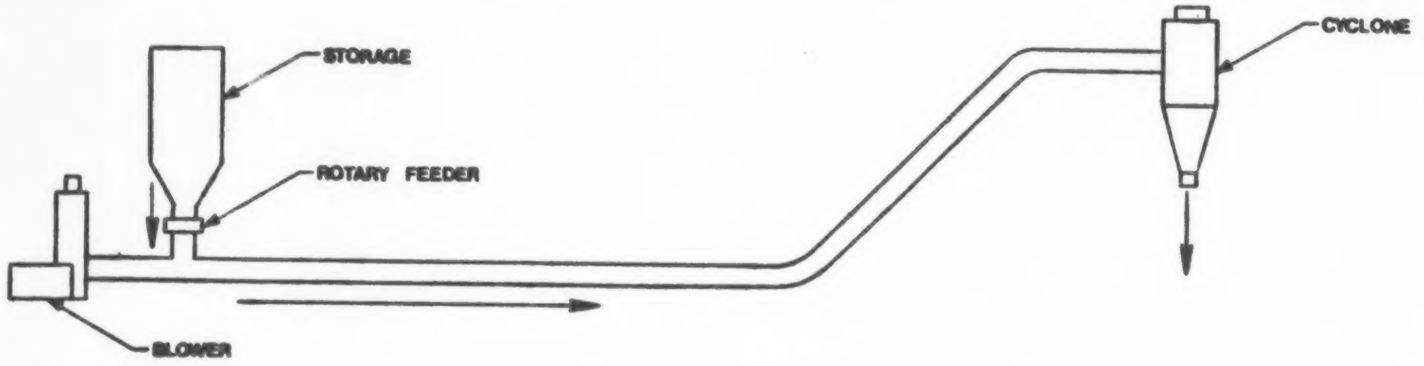

STORAGE
ROTARY FEEDER
BLOWER
CYCLONE

FIGURE VI-16 PNEUMATIC FEEDER ARRANGEMENT

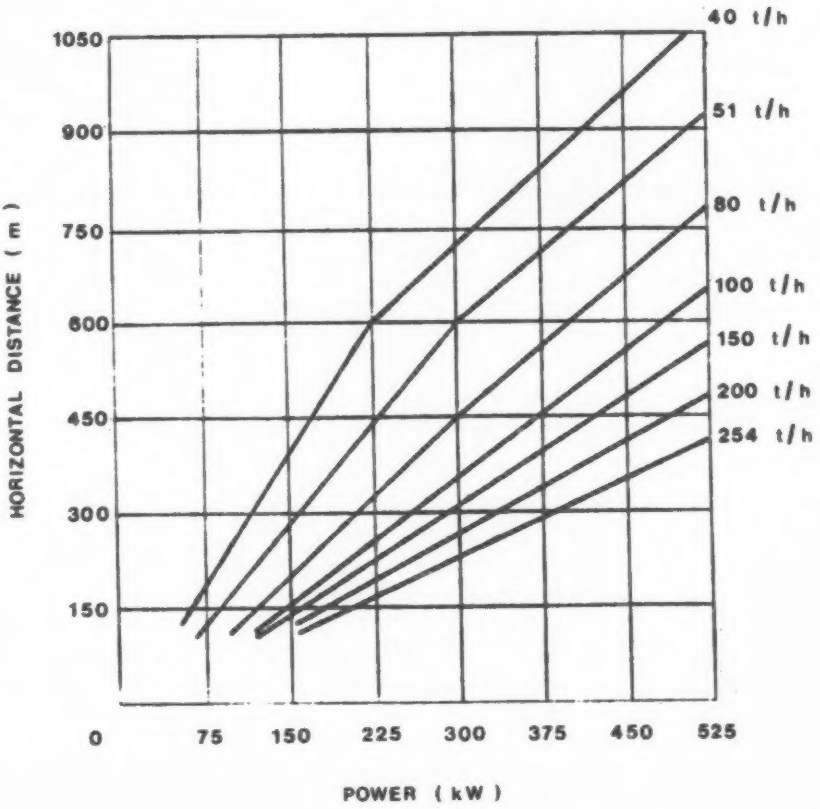


FIGURE VI-17 PNEUMATIC FEEDER POWER REQUIREMENTS

TABLE VI-8

Effect of Residue Characteristics on Selection of Equipment

Property or Characteristic	Used to Determine
Specific gravity	power and air requirements
Aerated specific weight	Bin and hopper volumes; feeder capacities
Sieve analysis - complete spectrum down to 325 mesh and average particle size	Dust collection requirements; feeder clearances; type of seals at points of air pressure differential; type of bearing protection required; power requirements
Abrasiveness relative to a commonly known abrasive material	Type of conveying system; materials of construction; type of feeder
Moisture contents	Type of conveying system; dust collection requirements; air drying and bin venting requirements; type of feeder; necessity for flow inducers in bins and hoppers
Tackiness relative to some well-known sticky material	Type of conveying systems; air drying and venting requirements; type of dust collection system
Aeration and deaeration characteristics	Type of conveying system; type of flow inducers in bins and hoppers; tupe of level indicator; design of chutes from bins and hoppers; requirements for deaeration
Angle of repose	Design of bins and hoppers; type of flow inducers in binns and hoppers
Temperature limitation	Requirements for cooling conveying air; insulation requirements for bins, dust collectors and ducts

Pneumatic feeder costs are dependent on capacity, distance of travel, and configuration complexity. Installed costs may range from approximately $10 to $30 per tonne per hour per meter length.

Pneumatic feeders may be used to convey wet or dry material sized to minus 5 cm. Problems with plugging may occur with wet or stringy material, especially if there are a number of elbows in the pipeline. Since pneumatic feeders are under pressure, they may suitably feed systems operating at low pressure.

3. Applications and Guidelines for Proper Use

Many pneumatic conveyors either operate below expected levels of efficiency or fail due to poor pipeline design. Specific detailed design of pipelines will, of course, vary for each application, however, there are several basic rules to consider in order to achieve efficient conveying, reduce pipeline wear and use minimum horsepower. These points of consideration are as follows:

1. Pipelines should be smooth, with no out-of-line joints.
2. No sudden change of direction such a mitered pipe sections or short radius elbows.
3. Avoid 90° turns and multiple turns close together.
4. No large changes in cross-section such as conical section which cause turbulence and reduce air velocity.
5. Wear surfaces must be smooth and resist erosion.
6. Pipelines should, whenever possible, be kept above ground. Those located below ground should have troughs which allow ready access.
7. Elbows and expansion joints should be easily removed.

Velocities utilized in pneumatic conveying systems for wood residues vary from about 1,500 m/min to 2,400 m/min. The lower velocities usually require less energy, but are more susceptible to plugging and other problems.

Pneumatic feeders are best applied to feeding dry homogenous material sized to minus 5 cm. Because of its variable size and moisture content, hog fuel is not recommended for pneumatic transport, although successful systems are in operation. Sand and other foreign inerts in hog fuel can cause very abrasive conditions in the pipeline and, consequently, a substantial increase in maintenance costs.

Pneumatic feeders are best used as intermediate feeders rather than directly to a wood conversion unit. Typically, these feeders charge surge or feed bins which then feed directly to the wood conversion system by gravity.

4. Status of Technology and Use

The major advantage of pneumatic conveyors are their versatility. They can readily convey material around corners, up inclines, over or under existing buildings and thus have few restrictions to their physical arrangement. Further advantages include long travel distance, low capital cost and minimal maintenance requirements.

The main drawback of pneumatic feeders is their tremendous power requirements. Furthermore, size degradation of materials during transport, dusting problems and high noise levels near air blowers may be encountered.

Pneumatic feeders are not attractive for direct feeding of pressurized reactors.

5. Manufacturers

Pneumatic conveying and feeding systems are composed primarily of a high-capacity blower and the pipe used to contain the air and suspended residues. Since the mills are all laid out differently, pneumatic conveying systems are all custom designed. As a result, the manufacturers of pneumatic conveyors tend to be fabricators and installers who purchase the required blower and air locks and maufacture the rest of the system according to individualy requirements.

There are some small systems that are available essentially off the shelf, but their capacities are usually too limited for applications in the forest products industry.

A list of companies who can design and install pneumatic feeding systems would include:

Sprout-Waldion Division of Koppers Company Inc.
Moldow
Rader Canada Ltd.
National Air Vibrating Company
ACO Sales & Engineering Ltd.
Petrocarb
CEA Simon-Day Ltd.
Riley Stoker
Sullivan Strong Scott Inc.
Macawber Engineering Ltd.

J. Ram and Piston Feeder

1. Design and Operating Principle

Ram feeders commonly refer to units which feed against near zero gas back-pressure. They consist of a reciprocating feed bar or ram moving within a tunnel or cylinder. No fittings are included to seal the gap between the ram and the cylinder and prevent gas leakage. Piston feeders are more refined than ram feeders, using basically the same reciprocating action to move materials, but adding a means of sealing to enable feeding against some back-pressure.

Ram and piston feeders are volumetric, positive displacement feeders and may be classified as follows:

- Ram feeders for low-pressure duty;
- Piston feeders for high-pressure duty;
    - Lurgi/Schlepper Feeder;
    - Ingersoll-Rand Co-axial Piston Feeder;
    - Conspray Dynamic Sleeve Piston Feeder;
    - University of West Virginia Rotary Piston feeder.

a) Ram Feeders

Ram feeders are used for both underfire and overfire feeding systems for combustors. Coal or wood residue is fed by a mechanical, hydraulically operated ram from a hopper, through a tunnel section into a combustion chamber (Figure VI-18).

The length of stroke usually remains constant and feedrate is controlled by ram cycles per minute and ram area. The ram may be either a feed bar with "shoes" attached or a solid piston to provide forward movement. The ram is usually fed from a hopper, although some suppliers utilize a metering system to the ram to prevent jamming and excessive shearing of feed material between ram and cylinder.

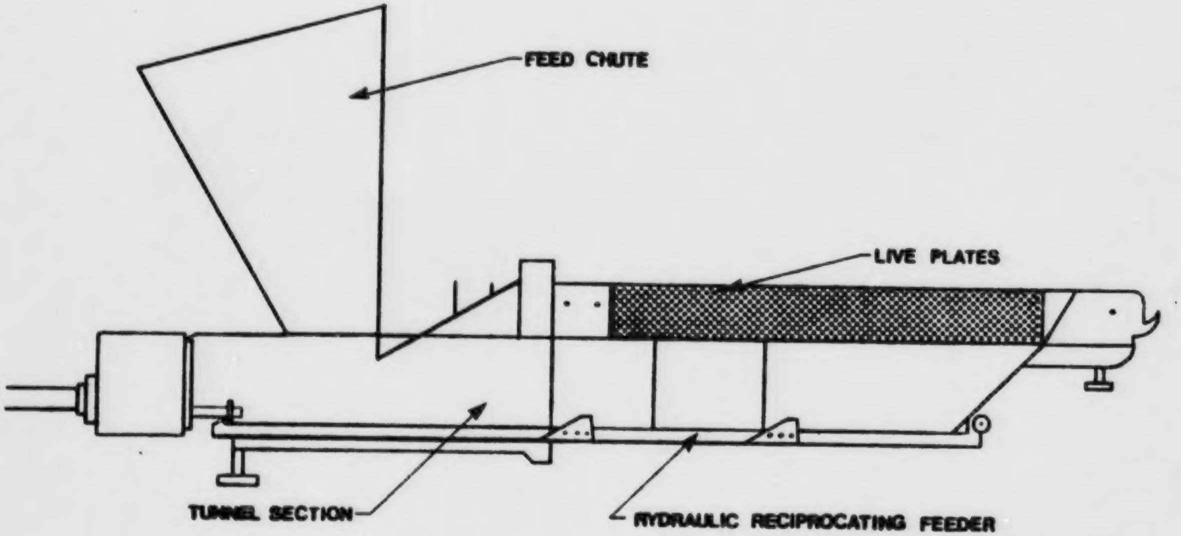

FEED CHUTE
LIVE PLATES
TUNNEL SECTION
HYDRAULIC RECIPROCATING FEEDER

FIGURE VI-18 UNDERFIRE STOKER

b) Piston Feeders

i) Lurgi-Schlepper Feeder

The Schlepper type system shown in Figure VI-19 operates essentially on the same principle as the lock hopper except that the function of the top valve is replaced by a sealing piston. The cylinder is filled with solids from a bunker with the piston in its upper end position and the bottom outlet closed. The cylinder is filled to a level below the lowermost part of the inlet chute, allowing the piston to return and seal the feed chamber, without compacting the solids. The cylinder compartment holding the solids is then pressurized with product gas. After pressure equalization, the bottom closure opens and the solids are pushed into the reactor while the piston moves to the lower end of the cylinder. When the bottom valve is closed, an insignificant volume of gas at reactor pressure is retained compared to the total feeder cylinder volume. After withdrawal of the piston, this gas is at reduced pressure. Apart from the drastic reduction of the vent gas rate, a further advantage of the system is quasicontinuous feeding, permitting a reduction of the intermediate volume in a gasifier and resulting in a lower gasifier height. A demonstration feeder based on the above design principles has been built and tested by Lurgi for coal feeding.

ii) Ingersoll-Rand Co-Axial Piston Feeder

The Ingersoll-Rand Co-Axial piston feeder refers to a feeder that makes use of pistons to transport solids and to displace process gas in a piston bore, while continuously maintaining a seal between the high-pressure discharge and the atmospheric inlet.

There are five steps in the single-acting piston feeder cycle as shown in Figure VI-20. In the first step, coal or other solids from the feed hopper fills the cavity between the delivery pistons. In the second step, the coal volume is in the mid-position with both coal pistons sealed in the bore. Process gas is introduced into the coal charge volume to pressure-equalize before the next step. During the third step, the pistons are in

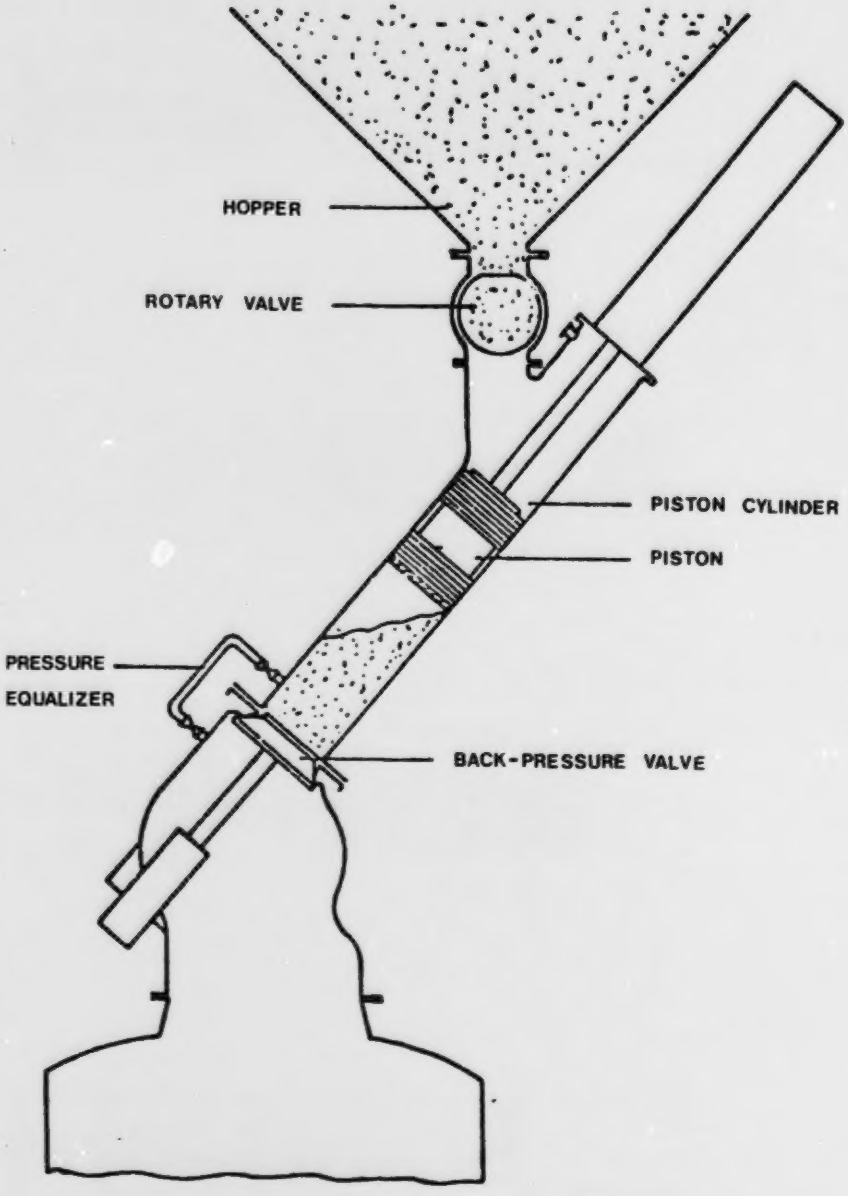
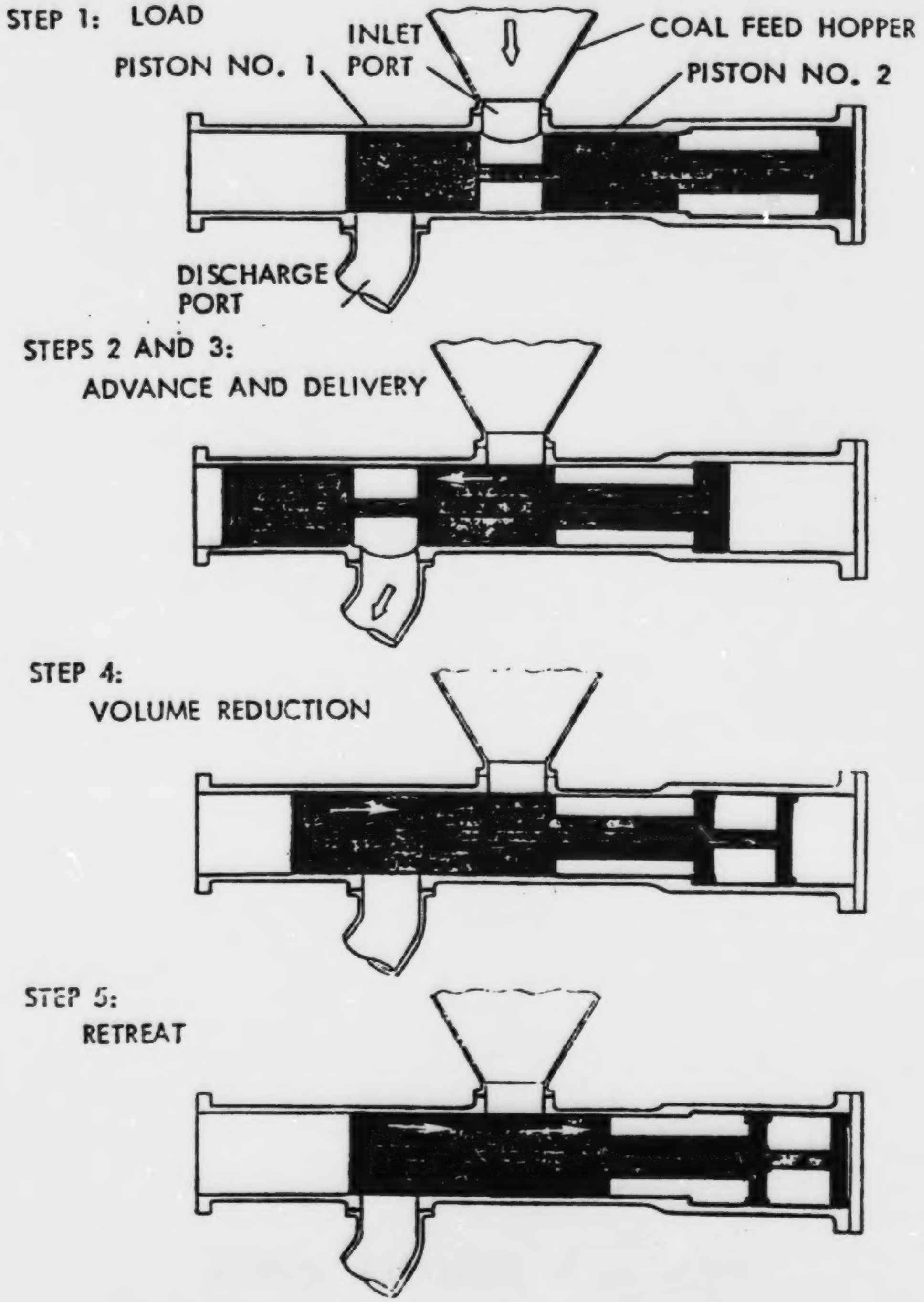

HOPPER
ROTARY VALVE
PISTON CYLINDER
PISTON
PRESSURE EQUALIZER
BACK-PRESSURE VALVE

FIGURE VI-19 SCHLEPPER FEEDER



STEP 1: LOAD

STEPS 2 AND 3:
ADVANCE AND DELIVERY

STEP 4:
VOLUME REDUCTION

STEP 5:
RETREAT

INLET PORT
COAL FEED HOPPER
PISTON NO. 1
PISTON NO. 2
DISCHARGE PORT

FIGURE VI-20 INGERSOLL-RAND PISTON FEEDER

in position over the discharge port. The fourth step shows the gas-exclusion piston advanced to mate with the coal transport piston displacing the gas. The pistons remain together until both are sealed in the bore. The fifth step shows the mid-position in which the pistons have been separated to expand residual process gas to reduced pressure. The separated pistons are then moved to the right in a position to receive the next charge.

The co-axial pistons are actuated by a hydraulic power supply.

The feeder is designed to maintain a seal at any stage of the delivery cycle and prevent release of gases from the reactor in the case of a malfunction.

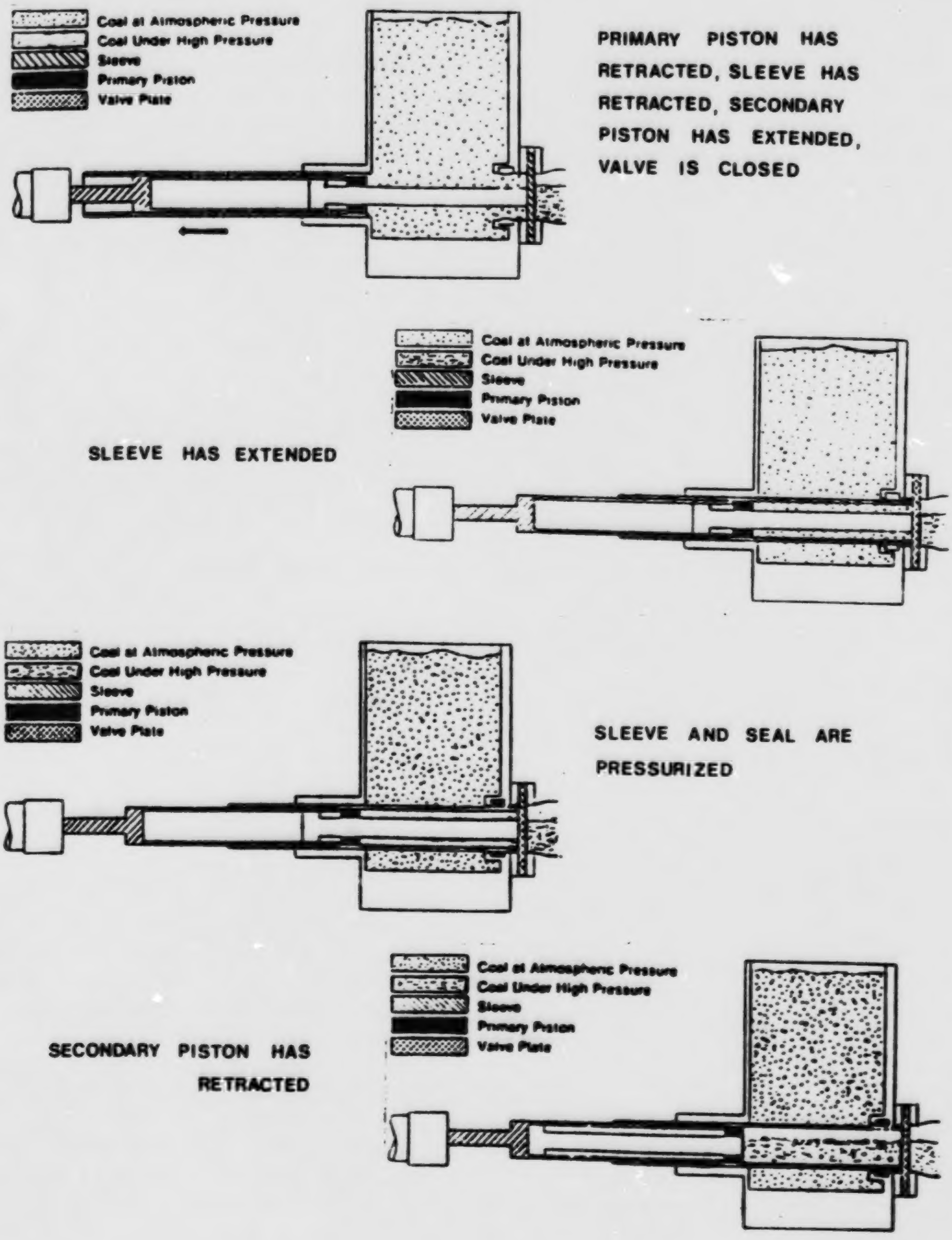
iii) Conspray Dynamic Sleeve Piston Feeder

The Conspray dynamic sleeve, piston coal feeder is a hydraulically-driven mechanical device capable of pumping a wide range of materials at elevated pressures. The full sequence of operations are shown diagrammatically in Figure VI-21. The feeder can also operate with a simplified feeding sequence.

At the start of the feeding cycle, the sleeve and piston are in a retracted position, flush with the rear of the material hopper. The tubular sleeve is extended forward through the hopper, charging itself with material as it travels toward the valve-end of the machine. The co-axial inner piston may or may not be extended, depending on the feeding characteristics of the solids.

The sleeve enters the valve assembly through a concentric seal around its outside diameter, called the sleeve seal. When it seats into the valve at the end of its stroke, the tubular sleeve is fully charged with material from the valve plate to the face of the pumping piston.

The valve into which the sleeve has seated is a pressurized housing with one moving gate sandwiched between two fixed plates, the entire stack being hydraulically loaded for sealing. Both surfaces of the gate are coated with tungsten carbide as are the


Coal at Atmospheric Pressure
Coal Under High Pressure
Sleeve
Primary Piston
Valve Plate

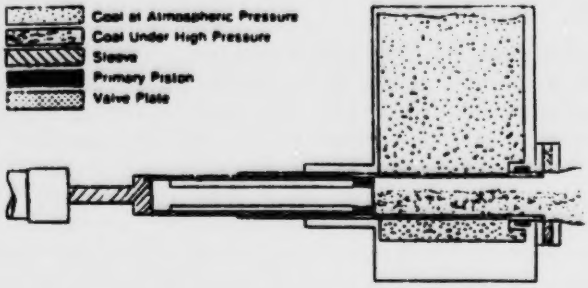
PRIMARY PISTON HAS RETRACTED, SLEEVE HAS RETRACTED, SECONDARY PISTON HAS EXTENDED, VALVE IS CLOSED

SLEEVE HAS EXTENDED

SLEEVE AND SEAL ARE PRESSURIZED

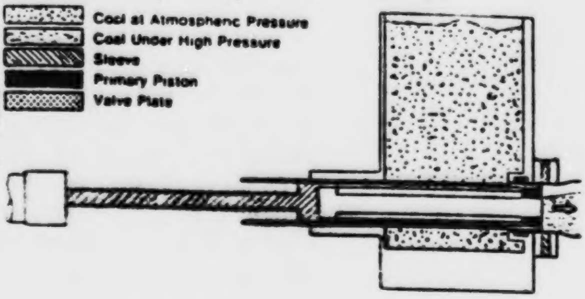
SECONDARY PISTON HAS RETRACTED

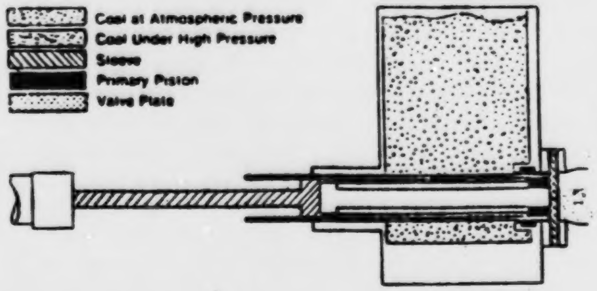
FIGURE VI-21 CONSPRAY DYNAMIC SLEEVE PISTON FEEDER


Coal at Atmospheric Pressure
Coal Under High Pressure
Sleeve
Primary Piston
Valve Plate

DISCHARGE VALVE HAS OPENED

PRIMARY PISTON HAS EXTENDED (HAS DISCHARGED COAL FROM THE SLEEVE)


Coal at Atmospheric Pressure
Coal Under High Pressure
Sleeve
Primary Piston
Valve Plate


Coal at Atmospheric Pressure
Coal Under High Pressure
Sleeve
Primary Piston
Valve Plate

DISCHARGE VALVE HAS CLOSED

SLEEVE SEAL HAS VENTED

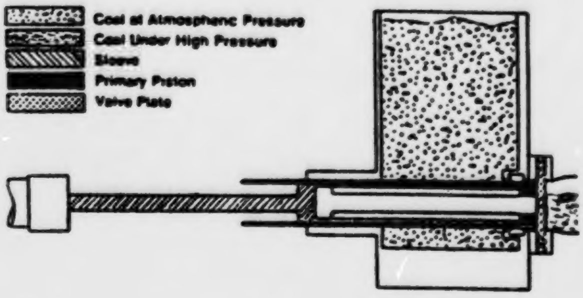

Coal at Atmospheric Pressure
Coal Under High Pressure
Sleeve
Primary Piston
Valve Plate

FIGURE VI-21 CONTINUED

sealing surfaces of the fixed plates. The housing is filled with hydraulic oil, and pressurized to a level somewhat above system pressure. The hydraulic loading on the plate is set to a similar level. Thus, material is hampered from getting between the plates and causing erosive wear that can result in valve failure. By maintaining a higher pressure in the housing than in the reactor some oil leaks into the system. Leakage rates are reportedly so low as to be inconsequential.

The interior of the sleeve, when initially charged, is still at atmospheric pressure and must be pressurized to system pressure. The sleeve has extended through the sleeve seal on its way into the valve and isolated the charge. This seal is now pressurized and is the barrier between atmospheric and system pressure. Once the pressure within the sleeve has been equalized with the system pressure, the gate may be shifted to the open position.

If no problems exist with packing of solids within the sleeve, then the inner piston may be left unextended at the start of feeding sequence. For these materials the inner and outer pistons can be operated simultaneously, forming one piston face. During the feeding part of the cycle, the piston face extends forward until it is in line with the mating surface of the fixed plate and the valve gate. Thus, all of the material is discharged into the system and the gate does not shear large particles upon closing. Smaller material does remain in th gate port, but the housing pressure prevents it escaping the port and it is reportedly not a problem.

The gate is then closed, the sleeve and sleeve seal are de-pressurized, and the sleeve and piston assembly are retracted into the far hopper wall, and the machine is ready to begin another cycle. The entire cycle is accomplished in approximately six seconds.

The second co-axial inner diameter piston is used for materials that tend to pack within the sleeve. On retraction, this secondary piston leaves a void in the material contained by the sleeve which allows collapse of the material and tends to prevent packing problems.

In operation, this secondary piston is left in the extended position when the sleeve and primary piston are retracted. The sleeve is then extended through the material as described previously, charging itself. Then the secondary piston is retracted until its face is flush with the face of the primary piston. At this point, the sleeve is charged with material, but with a significant void space. The void is uniformly distributed along the length of the sleeve.

After pressurization of the sleeve, the valve is opened to system pressure as previously decribed and the material is discharged. During this discharge stroke, the primary and secondary pistons extend as a single unit. After closing the valve, the sleeve and seal are de-pressurized and the sleeve and primary piston are retracted, while leaving the secondary piston extended. The cycle is then repeated.

In tests with coal no problems with packing were encountered, and it has not been necessary to utilize the secondary piston.

Because the creation of this void decreases the volumetric efficiency of the feeder, operation without the secondary piston is preferable.

iv) University of West Virginia Rotary Piston Feeder

A rotary piston feeder has been developed at West Virginia University. The feeder consists of a rotating disc containing a cylindrical injection chamber and a cam-activated reciprocating piston which provides the means for feeding into a chute agains the discharge pressure (Figure VI-22). The feeder operation sequence is as follows: Coal or other solids fill the open piston cylinder at top dead centre. The piston position relative to the cylinder then remains constant as the piston and its rotating housing move towards the discharge port. As the piston approaches the discharge port it is driven radially outward by the contact between the cams and followers forcing the coal through the discharge. During the next phase of rotation, the piston stays at the maximum outward position until it approaches the inlet port, returning to the

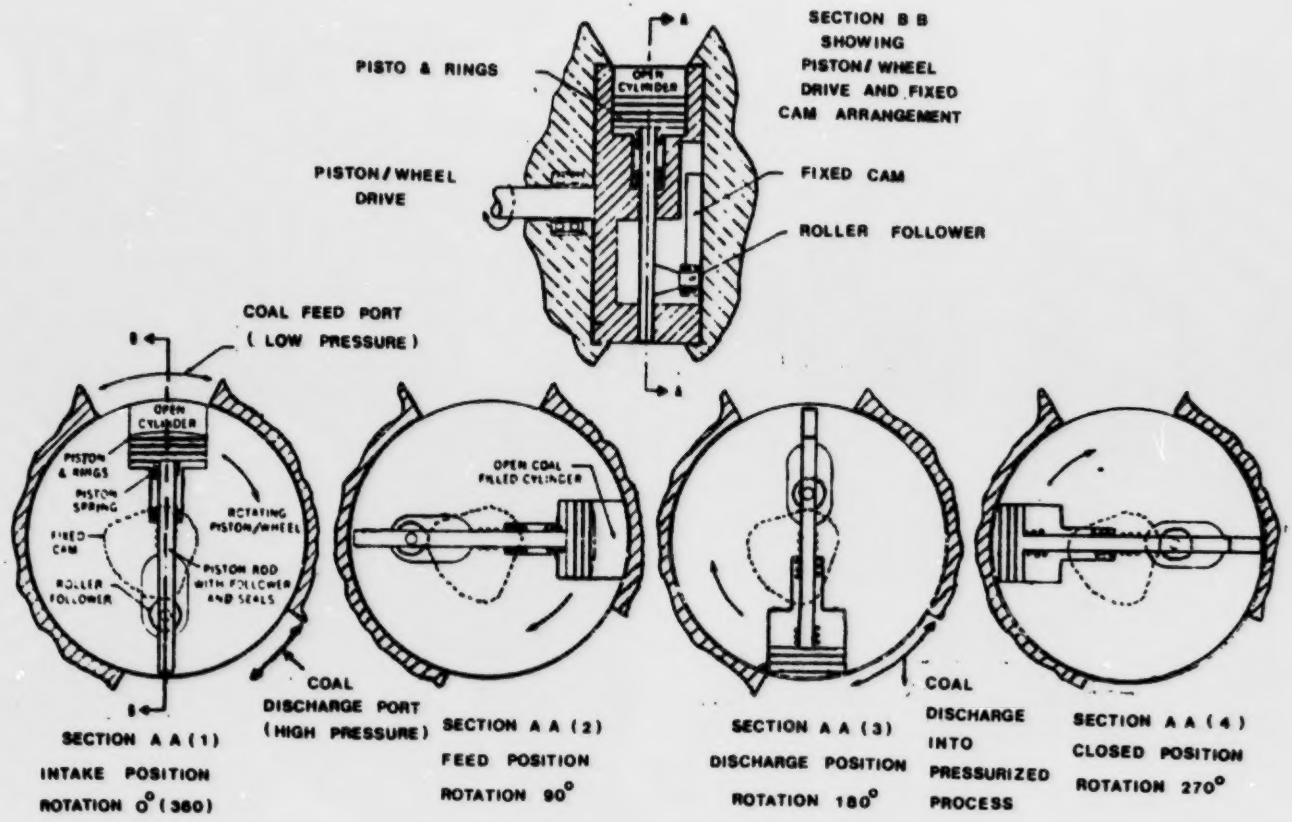

PISTO & RINGS
OPEN CYLINDER
SECTION B B SHOWING PISTON/WHEEL DRIVE AND FIXED CAM ARRANGEMENT
PISTON/WHEEL DRIVE
FIXED CAM
ROLLER FOLLOWER
A
B
COAL FEED PORT (LOW PRESSURE)
PISTON & RINGS
PISTON SPRING
ROTATING PISTON/WHEEL
FIXED CAM
PISTON ROD WITH FOLLOWER AND SEALS
ROLLER FOLLOWER
COAL DISCHARGE PORT (HIGH PRESSURE)
OPEN COAL FILLED CYLINDER
COAL DISCHARGE INTO PRESSURIZED PROCESS
SECTION A A (1)
INTAKE POSITION
ROTATION 0° (360)
SECTION A A (2)
FEED POSITION
ROTATION 90°
SECTION A A (3)
DISCHARGE POSITION
ROTATION 180°
SECTION A A (4)
CLOSED POSITION
ROTATION 270°

FIGURE VI-22 ROTARY PISTON FEEDER

loading position during the final phase of rotation prior to charging with coal.

The rotary piston feeder is still at an experimental stage of development. So far a casing for the feeder and three seals of different materials have been fabricated and tested.

Further development is required before the feeder can be considered for commercial use with coal.

2. Performance Characteristics and Costs

Performance characteristics of ram and piston feeders are summarized in Table VI-9. Characteristics such as feed size range, power requirements, capacity range, feed discharge pressure and status of development are tabulated. Volumetric feedrates have been converted to a weight basis of tonnes per hour (t/h) using densities of 300 kg/m^3 for wood and 800 kg/m^3 for coal.

Many of the high-pressure piston feeders are at a development or testing stage and have been designed for feeding sized coal to pressurized gasifiers. Because most of the new designs are recent developments, very little data concerning performance has been published.

The Schlepper piston feeder by Lurgi provides quasi-continuous feeding with a drastic reduction in the volume of vent gas that must be handled. It also allows the feed material to be transferred into a pressurized vessel without significant compaction, and has a height less than that needed for a lock hopper. It needs further testing to determine wear and power requirements.

The Co-axial piston feeder by Ingersoll-Rand Research Inc. seems to have significant advantages over all other feeders. There is no pressurized gas loss from the system. In addition, no coal preparation is needed and the character of the coal is not changed by the feeding process. It accepts all types of coal, as well as a wide range of particle sizes. A desirable feature is the fact that is is inherently "fail-safe" in the event of system malfunction. In conjunction with interlocks, the co-axial piston feeder ensures that the process is sealed.

TABLE VI-9

Characteristics of Ram and Piston Feeders

Manufacturer/ Developer	Size mm	Power Requirements kWh/t	Feed Material	Feed Size mm	Capacity Range t/h	Differential Pressure kPa	Status and Comments
LOW-PRESSURE RAM:							
Combustion Service & Equipment Co.		3.0	coal wood pellets wood residues	50	0.34-0.77	near zero	-Auburn stoker -commercial underfire stoker -multifuel boilers -hydraulic drive
Lamb-Cargate Industries Ltd.	to suit	38 (depends strongly on load to shear residues)	wood residues to 65% mc	75	0.6-8	3	-intergral part of wet-cell burner -commercial -underfire stoker
HIGH-PRESSURE PISTON:							
Lurgi			coal	all sizes to about 50 mm (estimate)	20	3,000 (estimate)	-Schlepper Feeder -requires testing for power requirements and wear
Ingersoll-Rand Research Inc.	229	3.7 @ 3,400 kPa back-pressure	coal to 25% moisture	0.075-25.4	2.27	3,447 (typical) 10,342	-Co-axial piston -4,000 hour bench test in 1980 with demonstrated stirred-bed gasifier -IRRI considers as universal feeder
Conspray Construction Systems Ltd.	114.3	4.2 @ 6,900 kPa back-pressure	coal to 30% moisture	50.8 (max.)	3	3,447 (typical) 8,620 (max.)	-Dynamic Sleeve Feeder -8 months of test (1981)
			wood		10 (estimate)		
ROTARY PISTON:							
University of West Virginia Dept. of Energy	127 piston 127 stroke 4,572 wheel		coal all types	wide range	1.4-9.6	6,895	-fabricated and tested -experimental -further testing and demonstration needed -30 rpm -1 to 8 cylinders

The Co-axial piston has undergone extensive development and has had about 4,000 hours of bench scale testing. Development work is continuing. A scraper on the pistons prevents contamination of seals. An energizing gas is used to provide uniform contact stress between piston and bore. A liner is used in the coal transport system to reduce wear.

The Dynamic Sleeve Feeder manufactured by Conspray was developed from knowledge and experience in concrete pumping technology. The feeder has successfully fed coal with a wide range of sizes and low moisture contents. and turndown ratio of about 10:1. The capacity of the dynamic sleeve system can be increased by using 2 or 3 cylinders. The feeder is rugged and has pumped foreign objects such as rocks and bolts. The special sealing valve at the sleeve outlet is a vital component of the design. Oil leakage at the seal plates on the gate valve has been minor. Wear of the feeder when handling coal has been small.

The Rotary Piston feeder by the Department of Energy, University of West Virginia, is still in the experimental stage of development. The main advantages of the rotary piston are its compact size, simplicity of operation, minimum loss of gas and variable capacity depending on the number of cylinders used in the unit.

Because most of the piston feeders are at a development or testing stage, few cost data are available. A Conspray Dynamic Sleeve feeder with a capacity of 3 t/h and suitable for 6,895 kPa back-pressure costs about U.S. $120,000 to U.S. $130,000 (1982).

3. Guidelines for Proper Use

Ram feeders for underfire and overfire feeding of combustion processes are well known and established. They are suitable for moderate to large sized fuels at slow feedrates. The most common fuels are granular coal and hogged wood residues. The Auburn stoker used on a Tri-fuel boiler supplied by Combustion Services and Equipment Co., handles coal as well as wood pellets, sawdust, sanderdust, and hogged wood residues with moisture contents of up to 65 % (wet basis). Hydraulic drive systems for ram feeders have suffered from problems with high pressure "hammer" in the hydraulic system when the ram changes direction at the end of each stroke. This causes repeated problems with hose failure and fatique of metal parts. A metering system should be used to feed the ram chamber to prevent jamming and excessive shearing of wood residues between the ram and the feed cylinder.

Piston feeders for high pressure conversion systems are fairly recent developments and most have evolved from work funded by the U.S. Department of Energy to develop feeding equipment for pressurized coal gasifiers. Since these feeders have been developed for feeding sized coal to pressurized gasifiers, they have not been tested to determine their suitability for feeding wood residues.

4. Applications

a) Non-Pressure Feeder

Underfire stokers such as the design used with the Lamb-Cargate Wet Cell combustor and designs marketed by Combustion Service Equipment Co. and other manufacturers of combustors and boilers are proven equipment for feeding wood residues to non-pressurized conversion systems and are only suitable for this type of duty.

b) Pressure Feeders

The Schlepper piston feeder, Co-axial piston feeder, Dynamic Sleeve feeder, and Rotary Piston feeder all are capable of feeding materials to pressurized fluid bed combustors and gasifiers. The co-axial piston and dynamic sleeve piston feeders can feed into pressure of up to 8,600 - 10,000 kPa with negligible venting of process gas. The fact that the feed material is not compacted is a positive factor and in some cases may allow more uniform distribution inside the pressurized reaction zone. While the Schlepper and Rotary Piston feeders are only able at present to feed into pressure of 3,000 to 7,000 kPa, they offer fairly compact designs.

Of the four identified pressure feeders only the Schlepper piston and Ingersoll-Rand Co-axial piston designs appear to have potential for feeding wood residues. Problems likely to be encountered when feeding wood residues with these feeders are poor flow into the feed chamber because of bridging in the inlet chute and within the feeder chamber, wear of the sealing devices due to contamination with sand and other foreign materials, and jamming with oversize materials unless designed to shear these pieces.

Both the Dynamic Sleeve piston feeder and the Rotary Piston feeder have features that make them unattractive for handling wood residues. The Conspray unit would require shearing of the residues during passage of the sleeve across the feeder hopper, making the design very susceptible to jamming and general malfunctioning for all but sawdust, shavings or other similar relatively small particles. It is expected that the Rotary Piston would be less efffective than a simpler rotary valve feeder.

5. Status of Technology and Use

There does not seem to be any promising new developments in ram feeders for non-pressurized systems.

The various solid fuel piston feeders offer considerable promise for pressurized systems. They are all in the developments stage however and more data on performance, reliability, power requirements and cost are needed. The Co-axial piston by Ingersoll-Rand Research has had the longest period under test.

Since none of the pressure feeders have been tested with materials other than sized coal, it is not possible to conclude with any confidence how they may feed wood residues, especially chipped or hogged materials. All of the designs may suffer from poor filling of the feed chamber.

The most promising pressure feeders are those developed by Ingersoll-Rand and Lurgi. Testing of these designs with wood residues is needed before their suitability can be determined.

6. Manufacturers

The following manufacturers and developers were included in this study:

Combustion Service & Equipment Co.
Conspray Construction Systems Inc.
Dayton Automatic Stoker Co.
Econo-Therm Energy Systems Corp.
Lamb-Cargate Industries Ltd.,
Ingersoll-Rand Research Inc.
Lurgi
University of Virginia, Dept. of Energy

K. Rotary Feeder

1. Design and Operating Principle

Rotary feeders are pocket drums or vane type devices used to feed flowable materials such as fines, pellets, sawdust, chips and other materials. Material is trapped in the pockets at the feeder inlet and discharged from the bottom of the valve by gravity. The rotary valve acts as a seal and metering device allowing rotary feeders to be applied in pneumatic or pressurized systems.

Feed rate is determined by the volume of the pockets and drum rotation speed.

Rotary feeders are particularly useful where gas sealing is a requirement in addition to feeding. Rotary feeders have been successfully used for gasifiers and wood residue combustors. Preferably, rotary feeders should be used where the residues are dry and do not exceed 5 cm in size, such as dry wood chips and dry fines.

Rotary feeders are available in a wide variety of designs, sizes and materials. Many have special features such as vanes that are adjustable, flexible, or replaceable housings that are jacketted for heating or cooling, and outlets to allow drop-through or blow-through discharge into pneumatic conveying systems.

Rotary feeders can be classified as:

Non-Pressurized and Low Pressure for General Duty

- drop-through
- inlet transition
- side inlet
- vented inlet

Low to Medium Pressure Feeders

High Pressure Feeders

- hydrotransport
- steam transport

It must be understood that equipment referred to in the following discussion are used as typical examples only. Equivalent equipment by other manufacturers are available and can be found in a list of manufacturers in this report.

a) General Duty Rotary Feeders

Basic components of a rotary feeder are shown for a Koppers Rotary valve in Figure VI-23. Three different types of rotary vanes, as well as several variants of housings and end plates are available.

Several housing designs are available to enable trouble-free operation for most types of materials.

i) Drop-Through

This configuration is the basic design in which feed enters the top of the feeder, fills the pockets, passes around the periphery with the rotating vanes and discharges by gravity from the bottom.

ii) Inlet Transition

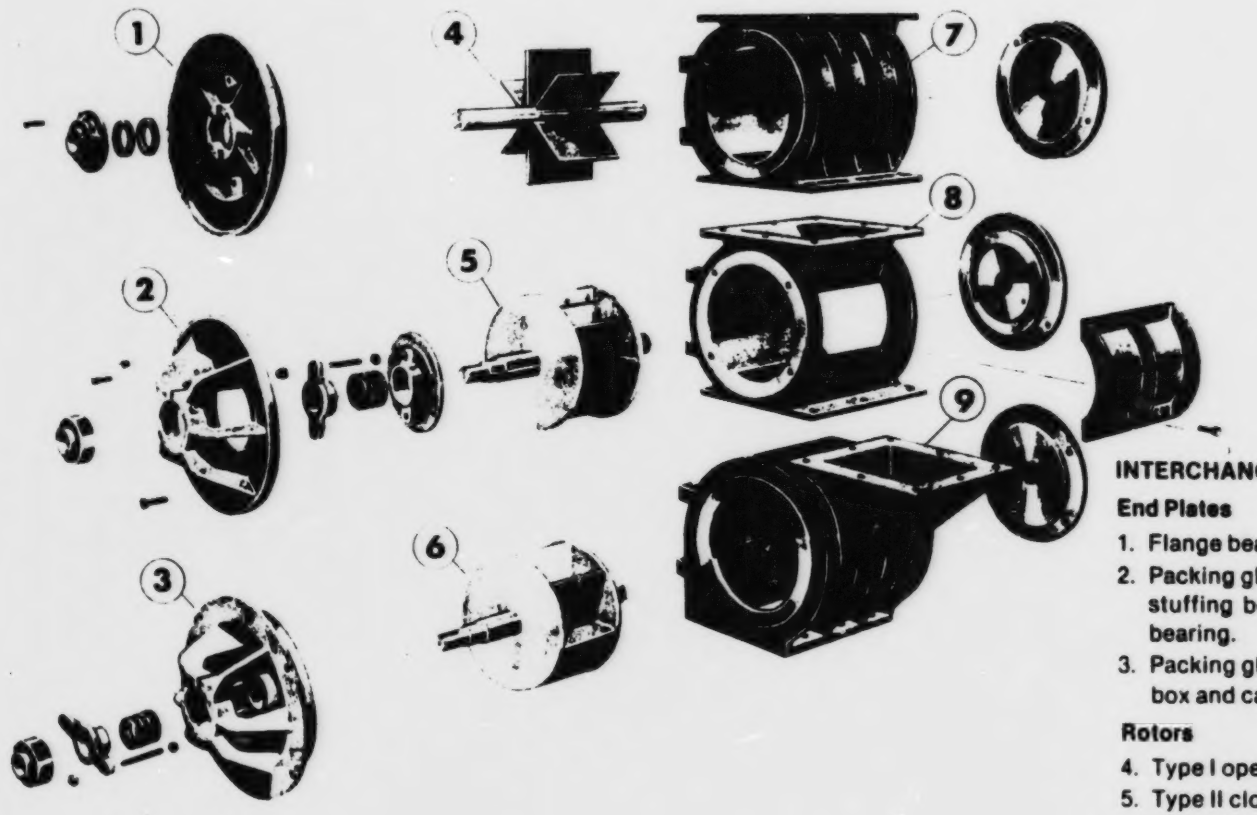
When rotary airlock valves are used to feed hard materials, such as pellets, excessive wear of the valve can occur unless the jarring, chattering action caused by the flow of the pellet is minimized. This can be done using an inlet transistion section. The pockets of the rotary air lock feeder are filled on the up-swing side of the rotor by closing off half of the housing through which material would normally flow to the feeder. This configuration is shown in Figure VI-24. As the lead vane of the pocket rotor passes the flexible wiper, excess material is removed so it does not come in contact with the shearing edge of the housing on the down-swing side.

iii) Side Inlet

The side inlet rotary feeder (Figure VI-25) is designed for feeding or metering hard pellets or fragile material. The side entry reduces incidence of shear or shock loading that hard material can impose on the valve metering gates, vent adapters and shear pin sprockets may be added.

iv) Vented Inlet

Because many rotary valves have metal-to-metal clearances, all feeders leak some gas when feeding into a pressurized vessel. The leaking gas tends to build gas bubbles which reduce flow of product into



INTERCHANGEABLE PARTS

End Plates

1. Flange bearing and lip seals.
2. Packing gland, separate stuffing box and cartridge bearing.
3. Packing gland, integral stuffing box and cartridge bearing.

Rotors

4. Type I open end.
5. Type II closed end with adjustable tips.
6. Type I closed end.

Casing

7. Without inspection panel.
8. With inspection panel.
9. Side inlet.

FIGURE VI-23 KOPPERS ROTARY VALVE

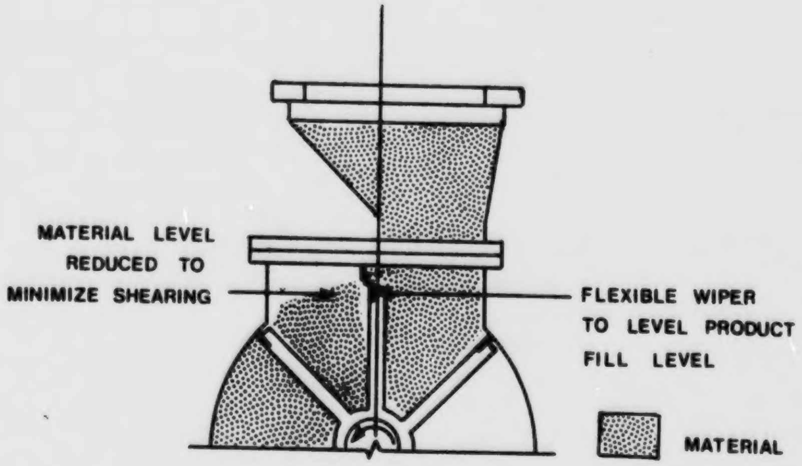

MATERIAL LEVEL
REDUCED TO
MINIMIZE SHEARING
FLEXIBLE WIPER
TO LEVEL PRODUCT
FILL LEVEL
MATERIAL

FIGURE VI-24 ROTARY VALVE WITH INLET TRANSITION

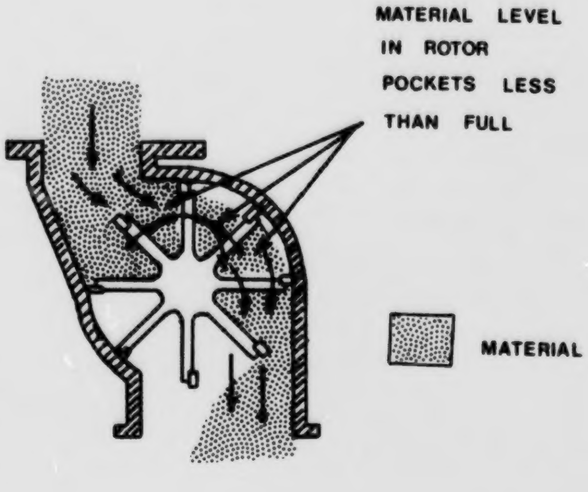

MATERIAL LEVEL IN ROTOR POCKETS LESS THAN FULL
▨ MATERIAL

FIGURE VI-25 SIDE INLET ROTARY VALVE

the feeder. In order to release the leaking gas an exhaust path may be provided at the inlet, Figure VI-26. This prevents gas from obstructing the flow of solids into the pockets of the feeder.

b) Low to Medium Pressure Rotary Feeders

These feeders use a tapered rotor and an appropriate liner to enable operation with minimal leakage under differential pressures up to 1,034 kPa. An example of this type of rotary valve is the Bauer unit shown in Figure VI-27. A rotor positioner is incorporated into the design to automatically adjust the clearance between the rotor and the liner to a value resulting in minimum gas leakage. An exhaust vent relieves the gas pressure in the pockets exposed to the receiving vessel prior to their return to the feed inlet so that the pressurized gas does not hamper material flow.

The Ingersoll-Rand feeder uses a steam jacket to assure even thermal expansion and, thereby, maintain close clearance. Each feed jacket has sharp hardened knives providing seal against the body at at least 8 locations from the high pressure side to the low pressure side in four zones of decreasing pressure. Only residual low pressure steam (or gas) is vented.

Kamyr Inc. markets the Asthma Feeder for feeding sawdust to digesters (Figure VI-28). In this design, sawdust fills a rotating pocket which is subsequently discharged into the pressurized digester using a blast of steam. The steam remaining in the empty pocket is vented to a low pressure recovery system before the opening in the rotor returns to the inlet position.

c) High Pressure Rotary Feeders

i) Kamyr Hydrotransport Feeder

A hydrotransport rotary feeder has been developed by Kamyr Inc. that allows operation with pressure differentials of up to 10,467 kPa. This unit is used to convey woodchips and coal from a near atmospheric pressure circulating stream to a high pressure stream. A simplied cross section of the valve is shown in Figure VI-29 to illustrate the principle of operation of each feed channel. The actual valve rotor contains four feed channels with eight holes arranged side by side in two groups of

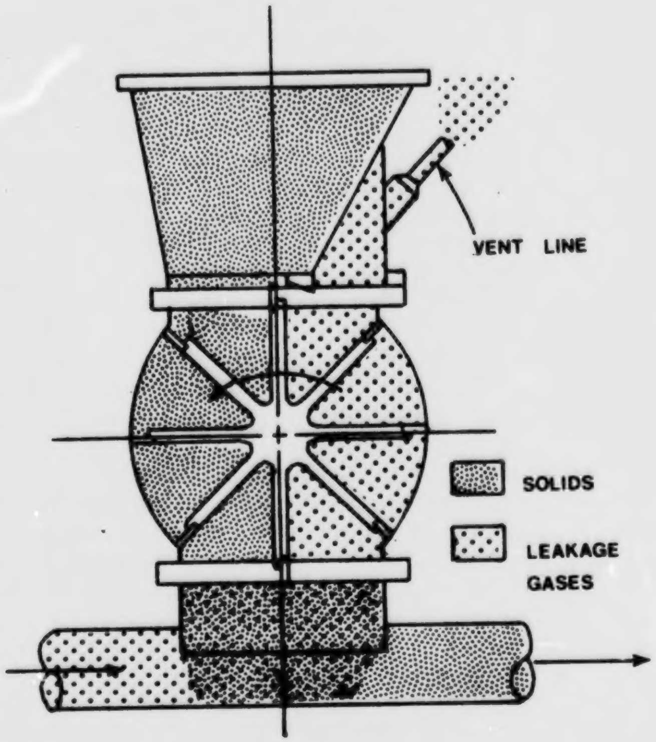

VENT LINE
SOLIDS
LEAKAGE GASES

FIGURE VI-26 VENTED ROTARY VALVE

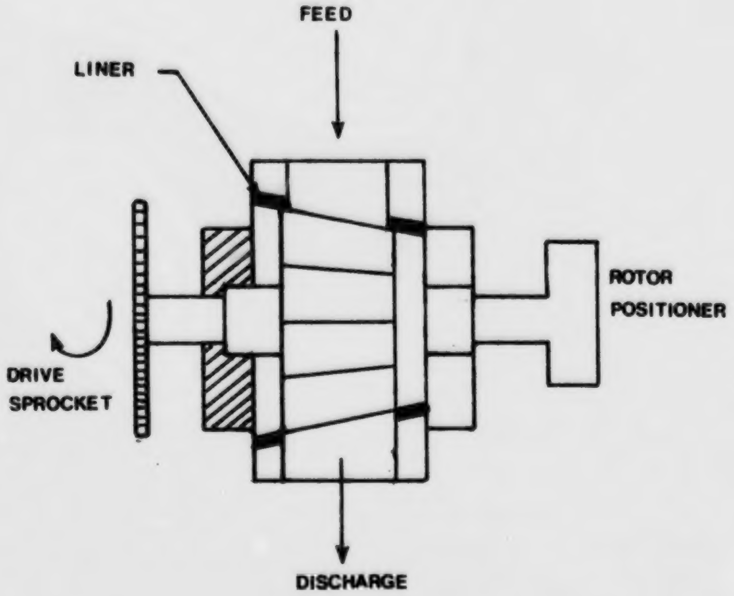
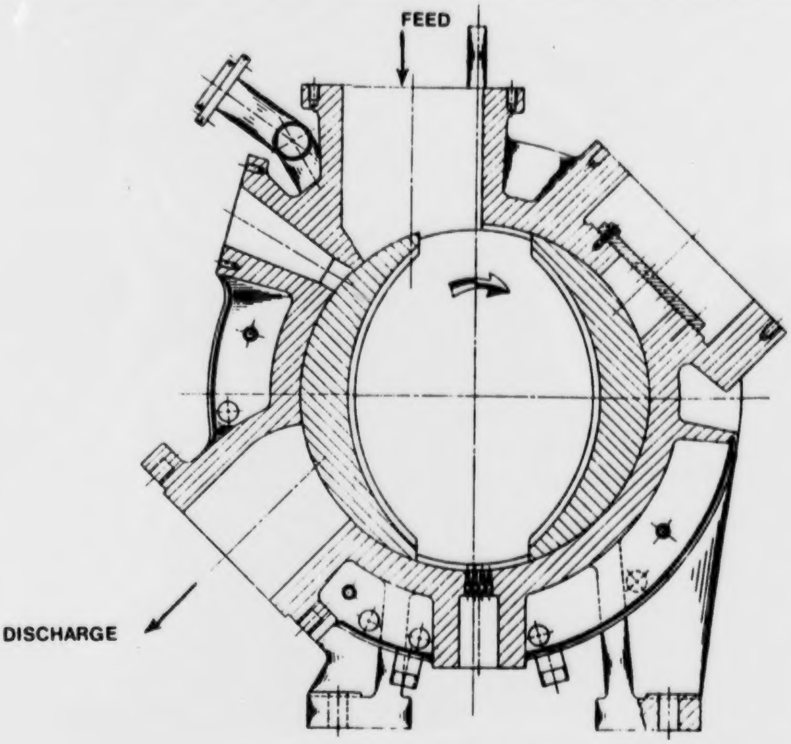

FEED
LINER
ROTOR
POSITIONER
DRIVE
SPROCKET
DISCHARGE

FIGURE VI-27 BAUER ROTARY VALVE


FEED
DISCHARGE

VALVE CROSS SECTION

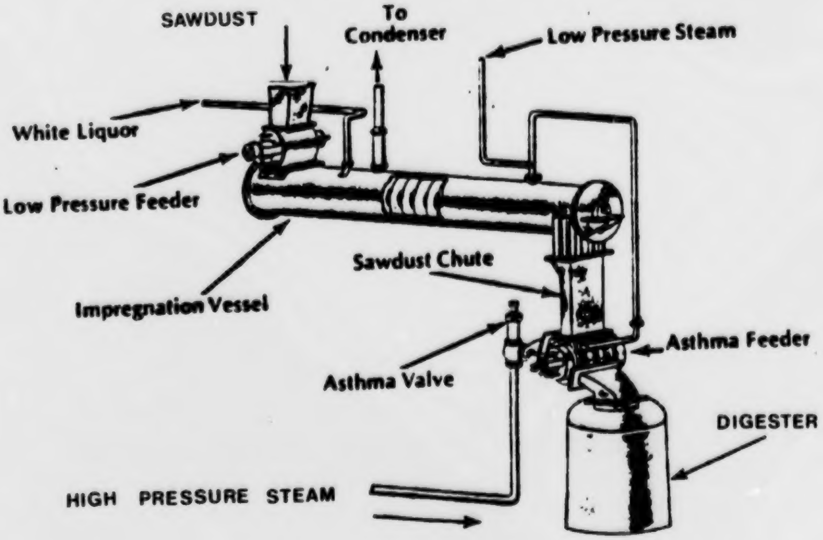
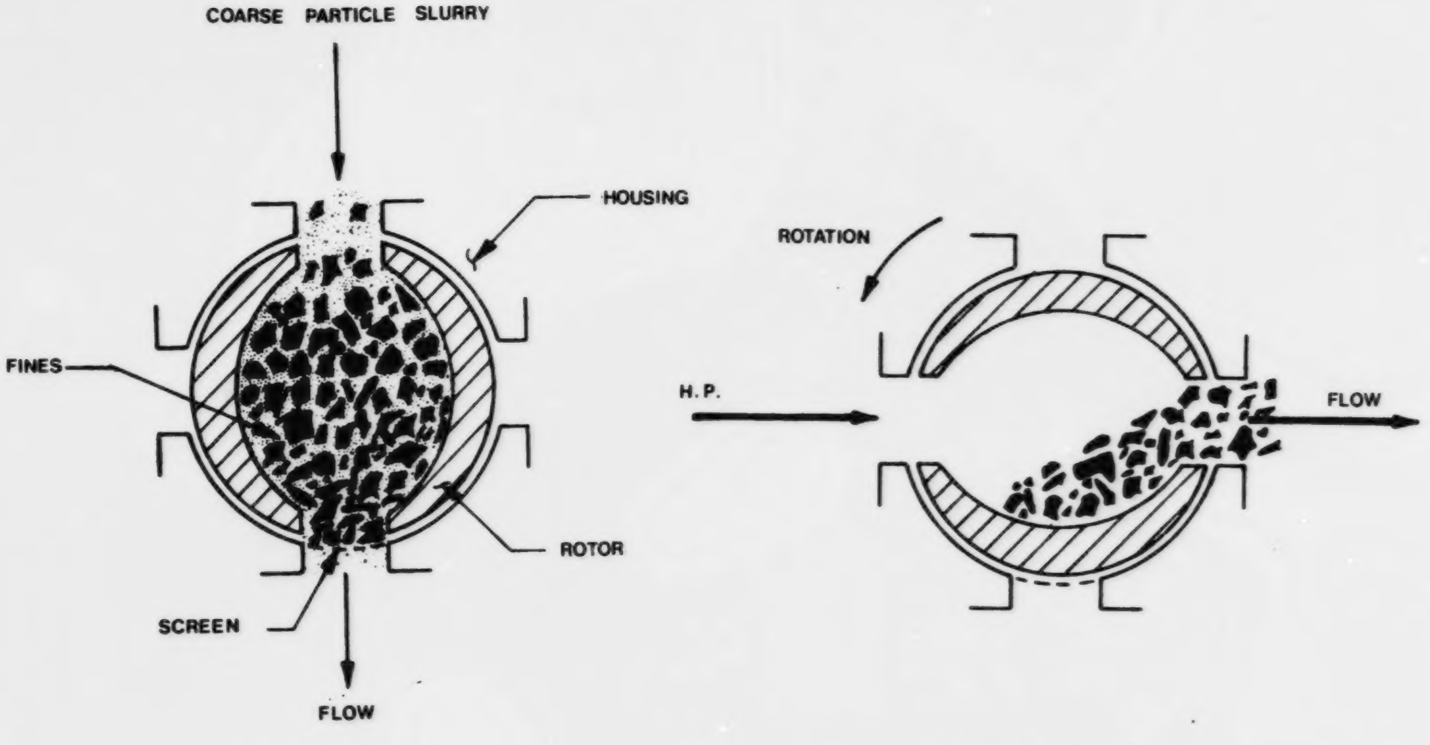

SAWDUST
To Condenser
Low Pressure Steam
White Liquor
Low Pressure Feeder
Impregnation Vessel
Sawdust Chute
Asthma Feeder
Asthma Valve
DIGESTER
HIGH PRESSURE STEAM

FIGURE VI-28 KAMYR ASTHMA FEEDER


COARSE PARTICLE SLURRY
HOUSING
FINES
ROTOR
SCREEN
FLOW
ROTATION
H. P.
FLOW

A. HOLE FILLING

B. HOLE DISCHARGING

FIGURE VI-29 CROSS SECTION OF ONE CHANNEL OF A KAMYR HYDROTRANSPORT VALVE

four. These four holes are placed 90° apart around the rotor, each pair of holes for a channel being diametrically opposed. The second set of four holes have the same arrangement, but are offset 45° from the first set of holes. At any time, one channel is filling, one channel is emptying, while the two other channels are in transit between the inlet and outlet ports. The rotor turns continuously, resulting in a continuous flow of solids and carrier fluids through the high pressure and low pressure ports. A self-cleaning screen covers the discharge port for the lower pressure stream to trap solds in the valve. Any fines passing through this screen are recycled with the circulated fluid.

A layout of a Kamyr hydrotransport feeder for supplying coal to a gasifier is shown in Figure VI-30.

ii) Beaumont Feeder

This company markets a special design of rotary feeder (SST Mark II) for use on high-pressure coal gasifiers. Designs are available for differential pressures of 2,400, 2,800, 4,100, up to 11,000 kPa. Because of experience with jamming of the feeder with large sizes of material, the company recommends feeding only particles having sizes less than 2.5 cm. A seal is achieved in the feeder with use of adjustable perphery seals attached to ends of the vanes. High-pressure gas returning in the empty valve pockets must be vented.

2. Performance Characteristics and Costs

Performance characteristics of rotary feeders are summarized in Table VI-10 using the following classifications:

- General Duty Rotary Feeders for Non-Pressurized or Low Pressure Systems
- Low to Medium Pressure Rotary Feeders
- High Pressure Rotary Feeders

Characteristics such as feed material, feed size range, capacity range, feed discharge pressure, and manufacturer are tabulated. All of the equipment is available commercially.

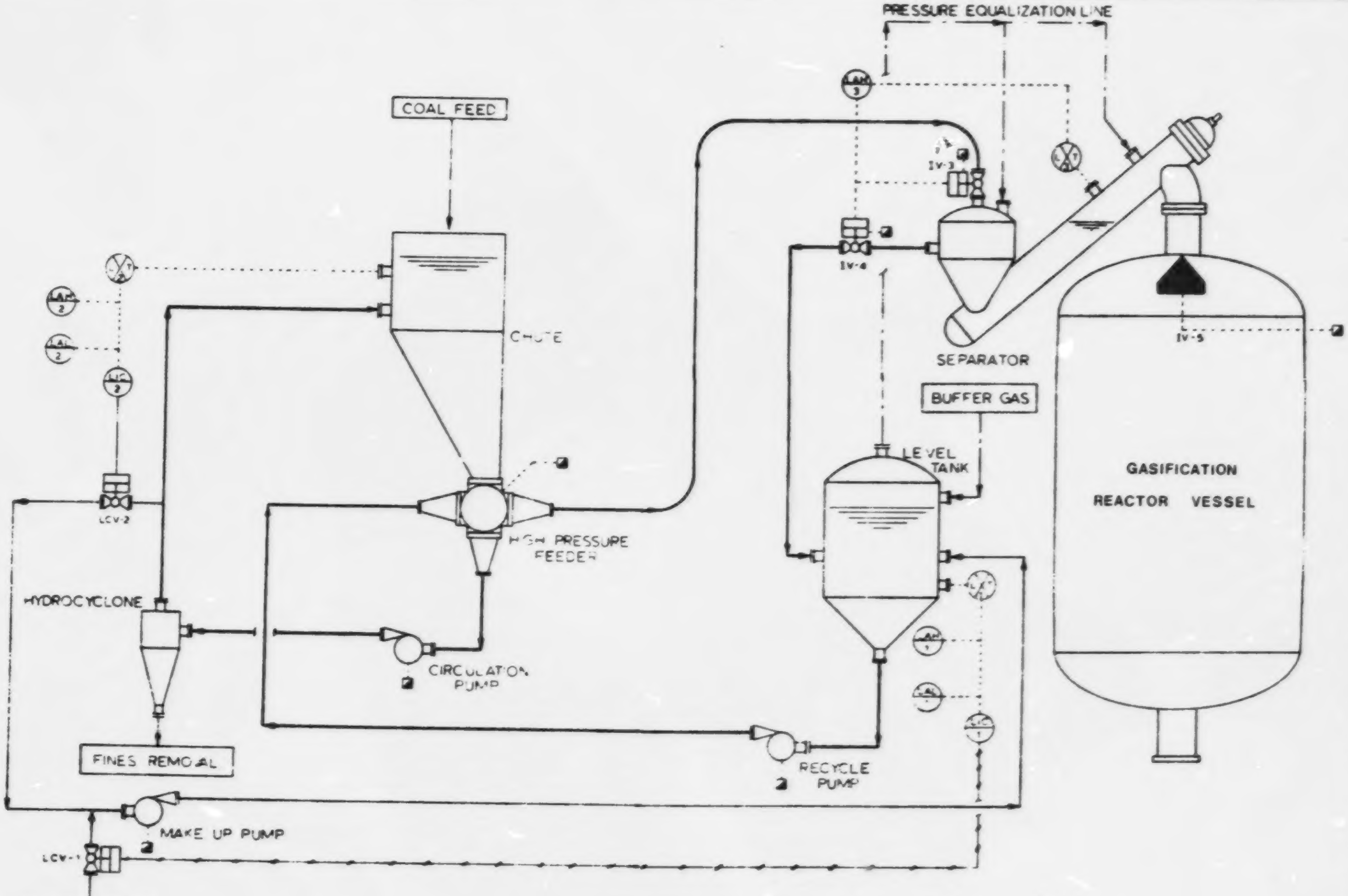

PRESSURE EQUALIZATION LINE
COAL FEED
LAH 2
LAL 2
LIC 2
LCV-2
CHUTE
HIGH PRESSURE FEEDER
HYDROCYCLONE
CIRCULATION PUMP
FINES REMOVAL
MAKE UP PUMP
LCV-1
WATER SUPPLY
LAH 3
IV-3
IV-4
SEPARATOR
BUFFER GAS
LEVEL TANK
LAH 1
LAL 1
LIC 1
RECYCLE PUMP
IV-5
GASIFICATION
REACTOR VESSEL

FIGURE VI-30 KAMYR HYDROTRANSPORT FEEDER FOR A COAL GASIFIER

TABLE VI-10

Characteristics of Rotary Feeders

Manufacturer	Rotor Size Dia. X Length (mm)	Feed Material	Feed Size (mm)	Capacity Range (t/h)	Differential Pressure (kPa)	Comments
GENERAL DUTY:						
Aco Ltd.	304 X 254 1,372 X 2,286	wood chips, hog fuel, sawdust	<75 <75 10	5.9-835	48	-Blow-through with shear knives
B.F. Gump Div. Blaw-knox Ltd.		wood chips, chemicals foods, (easily bruised materials		3.5-24.5	0	-Staggered pockets for steady delivery
CEA Simon-Day Ltd.		many materials		2.1-22.4	138	-pneumatic airlock
Clarke's Sheet Metal		unscreened wood residues		27-218	55	-pneumatic airlock
Fuller Co.		dry, granular	<76	0.8-52	344	-pneumatic airlock
Industrial Equipment Co. Ltd.	508 X 689 and others	hog fuel, bark,	<75	11-50	0	
Kamyr Inc.		wood chips			138	
Koppers Company, Inc.		many materials		0.3-138	68	

TABLE VI-10 (continued)

Characteristics of Rotary Feeders

Manufacturer	Rotor Size Dia. X Length (mm)	Feed Material	Feed Size (mm)	Capacity Range (t/h)	Differential Pressure (kPa)	Comments
GENERAL DUTY:						
Prater Industries Ltd.		wood flour, sawdust		1.4-25	103	-Pneumatic airlock
Rader Companies Ltd.	355 X 457 to 889 X 1,400	wood chips,	<75	14-319	55	-Pneumatic airlock
Semco Inc.	203 Dia. to 609	wide range, granular		0.02-3.5	174	
Wm. W. Meyer & Sons Inc.	762 X 762 to 1,219 X 1,219	cellulose, sawdust, wood chips		64-270	8.8	-Large volume, low density feeder
LOW TO MEDIUM PRESSURE						
C.E. Bauer	406 dia. to 914 dia.	wood chips, sawdust	38 X 3.2	3.4-113	1,034	
Beamont Feeders Inc.		wood, coal, abrasives, sticky matter	25	0.11-7.8	345	
Ingersoll-Rand Inc.	762 dia. to 1,320 dia.	wood chips		22.7-181	1,034	-Steam jacket, pressure equalizing
Kamyr, Inc.		wood chips		22-52	1,034	-Asthma feeder
Koppers Co. Inc.	762 X 559	coal		32	1,034	

TABLE VI-10 (continued)

Characteristics of Rotary Feeders

Manufacturer	Rotor Size Dia. X Length (mm)	Feed Material	Feed Size (mm)	Capacity Range (t/h)	Differential Pressure (kPa)	Comments
HIGH PRESSURE:						
Beaumont Feeder Inc.		coal	<25		2,413-11,000	-STT Mark II
Kamyr Inc.		wood chips, coal		48-185	2,413	- Hydrofeeder

Volumetric capacity data has been converted to weight capacity for wood in metric tonnes per hour (t/h), using a density of 320 kg/m^3 and assuming pockets are 100 percent full.

Power requirements in kilowatts have been plotted against capacity and are shown in Figures VI-31 and VI-32.

The pocket fill efficiency of rotary air-lock feeders is determined by the flowability of the material and the speed at which the rotary air-lock is turning. Typicl fill efficiencies for two types of products are shown in Table VI-11. While these percentages are used as guidelines, performance may vary due to such differences as fluidization, hopper discharge design, rotary air-lock vane clearance and system piping configuration.

All rotary feeders have some leakage associated with clearances required for operation (static leakage) and the displacement of air during rotation of the rotor (dynamic leakage). In many cases the largest component of leakage is static leakage. In most applications at typical speed of 15 to 20 rpm, dynamic leakage adds about 20 percent more leakage. Static leakage of a rotary valve is dependent on operating differential pressure and feeder size. Typical static leakages based on average clearances of various sizes of typical good quality rotary valves are shown in Figure VI-33.

Typical costs for non-pressurized and pressurized feeders are plotted against capacity in Figure VI-34 for late 1981 and the first few months of 1982. (Marshall and Steven Index = 736.4).

3. Guidelines for Proper Use

Rotary feeders are widely used as volumetric feeders to transport flowable solids from one vessel to another. If used as a metering device the fill efficiency of the pockets must be carefully considered. As shown in the previous section, fill efficiency decreases as the bulk density decreases and as the speed of rotation increases. Fill efficiency is also lower for fine powdery material than for granular material.

One of the main functions of rotary feeders is to minimize gas flow between vessels maintained at different pressures while at the same time allowing solid flow between them. As shown in the previous section, some gas leakage is inherent to the rotary feeder design depending on pressure differential and feeder size. This gas leakage should be vented to avoid reduction of the feed rate. If gases are hazardous or toxic,

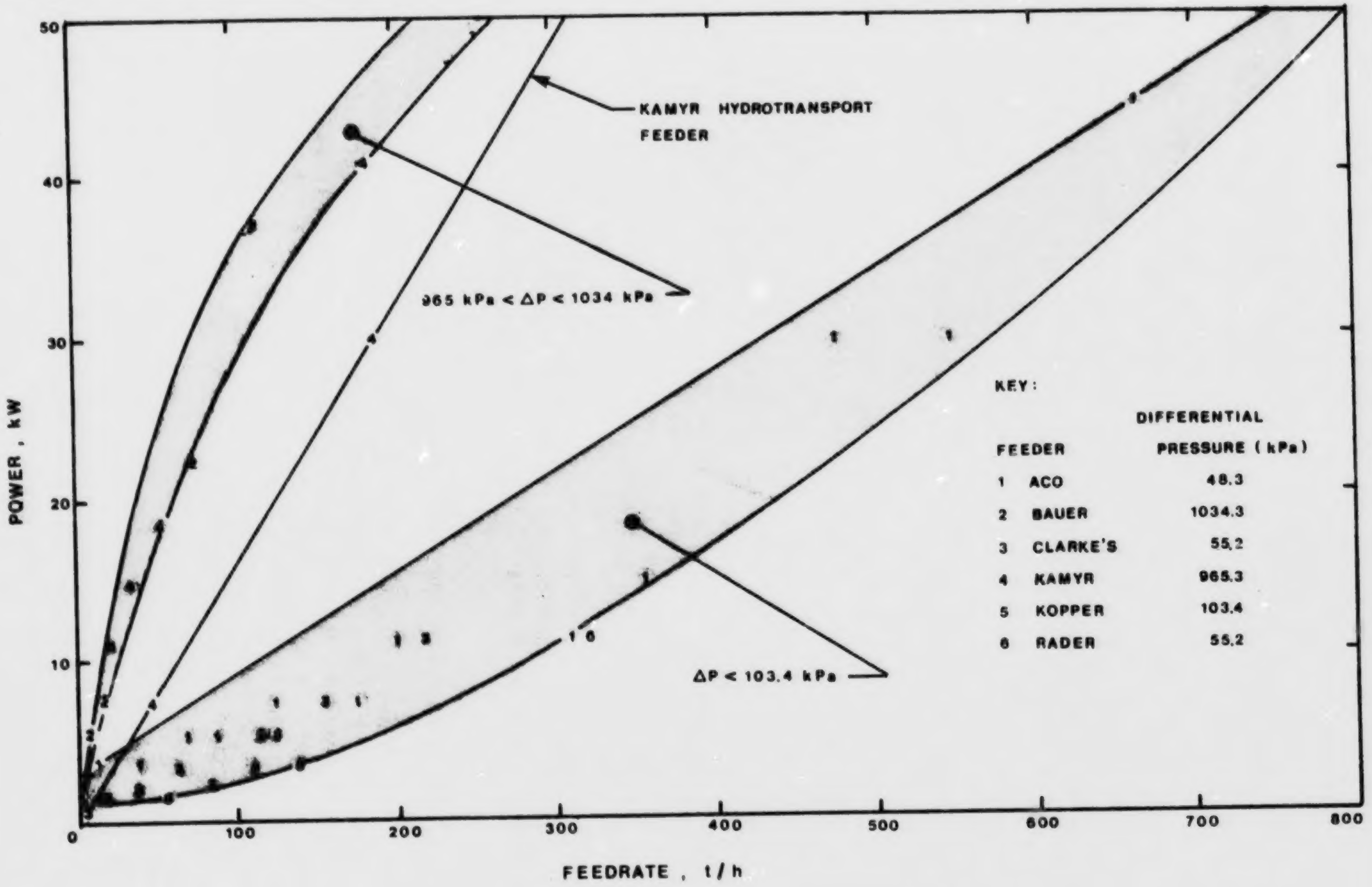


FIGURE VI-31 POWER REQUIREMENTS OF ROTARY FEEDERS (TO 800 t/h)

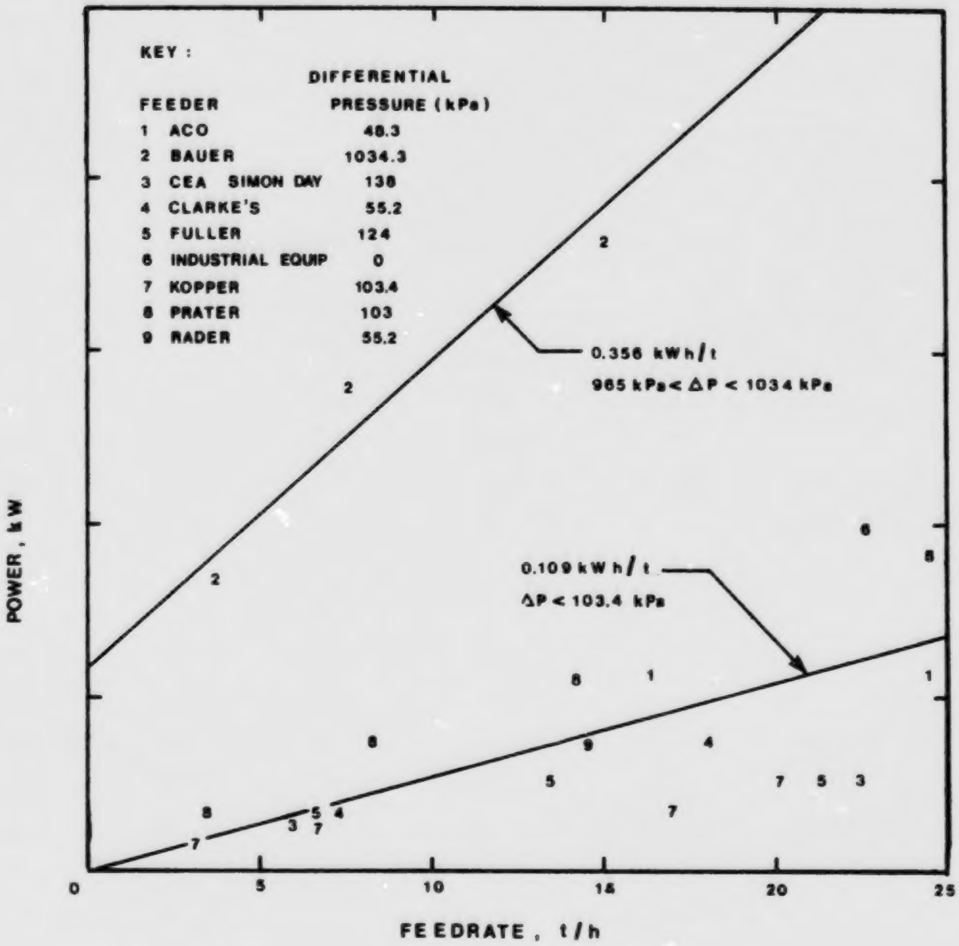


FIGURE VI-32 POWER REQUIREMENTS OF ROTARY FEEDERS (TO 10 t/h)

TABLE VI-11

Typical Pocket Fill Efficiencies for Rotary Feeders

Valve rpm	Efficiency (%) Average Bulk Density kg/m^3 (lb/ft^3)					
	160 (10)	320 (20)	480 (30)	640 (40)	800 (50)	960 (60)
			GRANULAR AND PELLETIZED MATERIAL			
5	80	90	100	100	100	100
10	70	85	95	95	100	100
15	65	80	90	90	90	95
20	60	80	85	90	90	90
25	55	75	80	85	85	85
30	50	70	75	80	80	80
			FINE AND POWDERED MATERIAL			
5	70	80	85	85	90	90
10	65	75	80	80	85	85
15	55	70	75	75	80	80
20	50	65	70	70	75	80
25	40	60	65	70	70	75
30	35	50	60	65	70	70

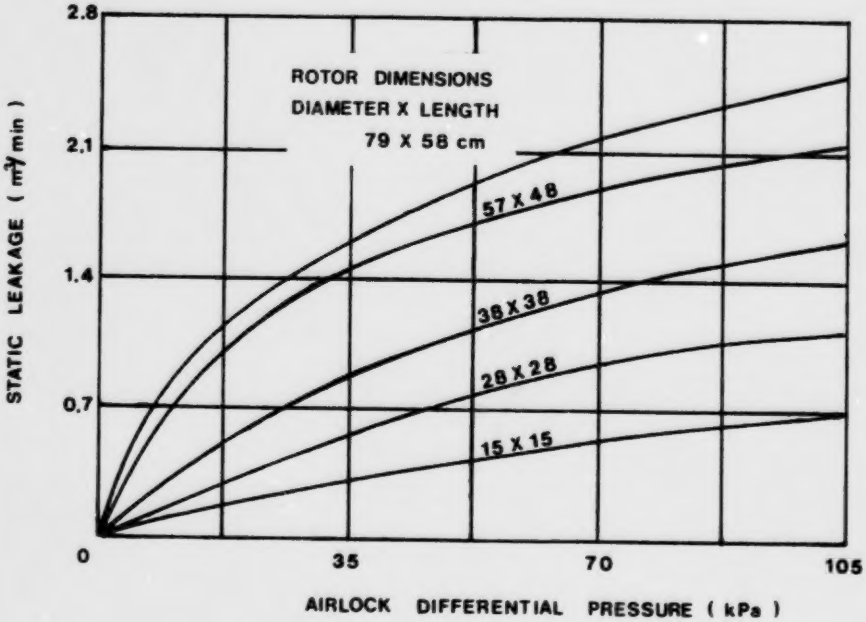


FIGURE VI-33 TYPICAL STATIC LEAKAGE FROM ROTARY AIRLOCK.

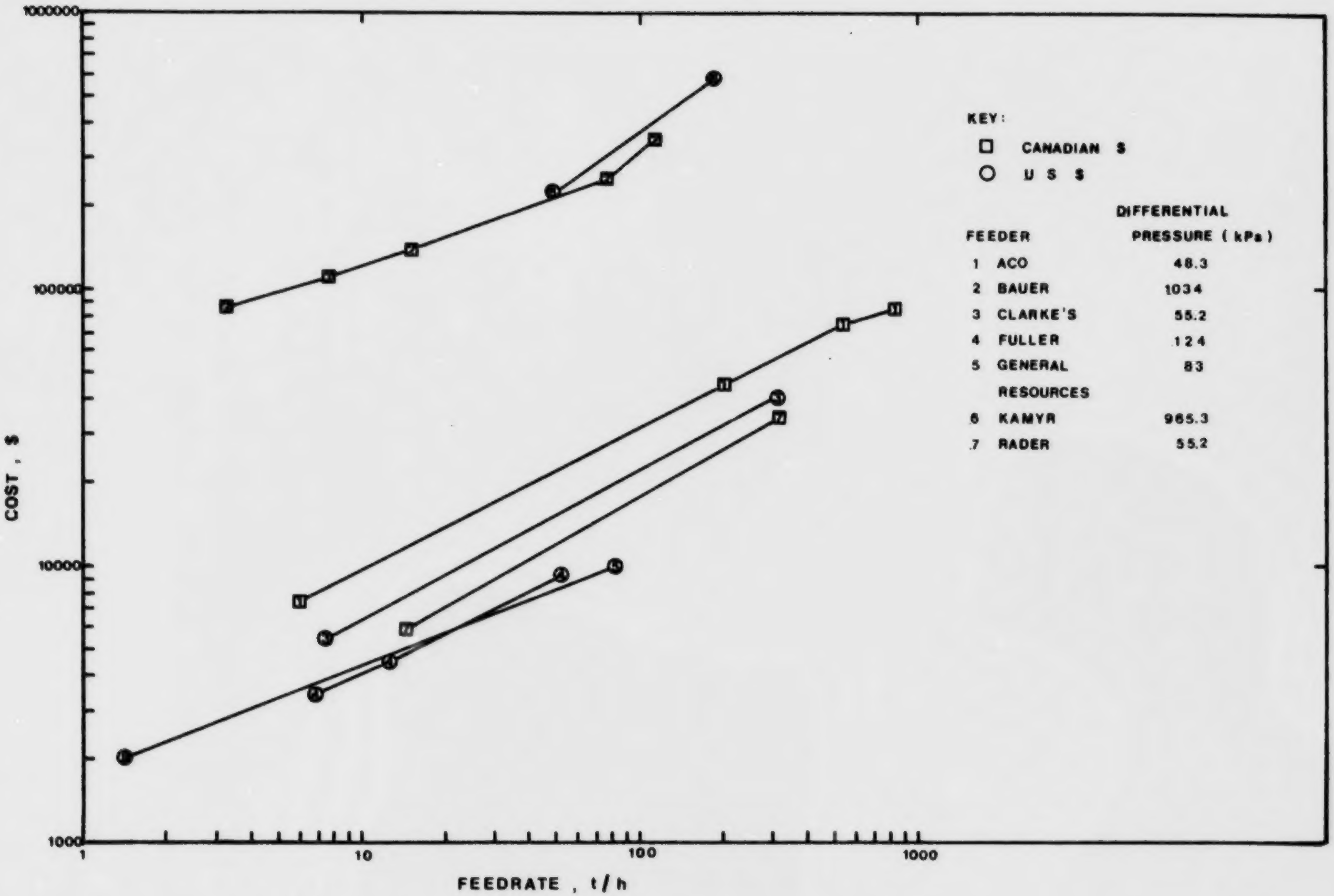


FIGURE VI-34 COSTS OF ROTARY FEEDERS

the vent gas must be handled in an appropriate manner such as venting steam to low-pressure systems and recycling hazardous gas to process or to scrubbers, etc. Generally, rotary feeders are not suitable for sticky moist or resinous materials, although self clearing feeders such as the Asthma and Hydrotransport feeders made by Kamyr can handle these troublesome materials adequately.

The advantages of rotary feeders are:

- positive volume control with good feedrate control;
- few moving parts and low space requirement;
- ability to seal when feeding energy conversion sytem.

Disadvantages of rotary feeders are:

- vulnerable to sticking of moist and resinous material and plugging of valve pockets;
- requires skilled labour to repair;
- must be manufactured to high standard for good performance;
- vulnerable to bridging in feeder chute at valve inlet;
- vulnerable to severe damages due to jamming by metals, resulting in long downtime. Can also jam with oversize residues;
- wear reduces sealing ability of valve;
- difficult to see or check condition of vanes.

4. Applications

The distinguishing feature of rotar feeders is their ability or inablity to feed against a differential pressure while minimizing the leakage of gases or vapours. The following discussions present information on feeders catagorized according to their ability to feed against pressure. Nonpressurized and low pressure feeders can only be used for this application while pressurized feeder could be used for either application.

Non-pressurized and low-pressure general purpose feeders can be used for feeding wood across a near zero diffential pressure. They can be used to feed boilers and combustors that operate at a slight negative pressure. They can also be used on low pressure gasifiers and pyrolyzers operating at negative or slightly positive pressures although care must be exercised to ensure any leaking gases are vented safely. The general purpose feeder is also widely used to feed wood residues into a pneumatic conveying system.

Medium-pressure feeders with gravity discharge such as those offered by C.E. Bauer, Beaumont, Ingersoll Rand and Koppers could be used on pressurized gasifiers operating with pressures of up to near 1,000 kPa. The vented gases containing carbon monoxide would have to be contained by the use of a purge gas or recycled to the process. The Asthma feeder offered by Kamyr Inc. require the use of steam to discharge the solids, a requirement that would be unattractive for most wood gasifiers since ample moisture for gasification is contained in the wood.

The high-pressure feeders offered by Beaumont Feeder Inc. function in a manner similar to the low- and medium-pressure rotary feeders, but are designed with special perpheral seals to allow operation up to 11,000 kPa pressures. The Hydrotransport high-pressure feeder developed by Kamyr Inc. could be used to feed high-pressure gasifiers up to about 2,000 kPa. However, a de-watering device would be needed before the wood could pass to the gasifier. This feeder is attractive for direct liquefaction processes which use a carrier liquid for transport of the wood during processing.

5. Status of Technology and Use

From the foregoing, it can be seen that numerous rotary feeders are commercially available for feeding wood residues to atmospheric and low-pressure conversion systems. There are also several rotary feeders commercially available for feeding medium-pressure (to 1,000 kPa) and high-pressure (to 11,000 kPa) conversion systems.

a) Non-Pressure or Low-Pressure Feeders

There does not seem to be any promising new developments in low-pressure rotary feeders for wood residues. One useful development might be to incorporate shearing knives or rotary blades to minimize the potential for jamming of irregular pieces of wood in hogged fuel.

b) Pressurize Feeders

Rotary feeders offered commercially by C.E. Bauer, Beaumont, Ingersoll Rand, and Koppers can discharge by gravity into pressures in the range of 345 to 1,034 kPa. To date, the unit designed by Koppers has been tested with coal, but not wood residue. All have configurations for equalizing pressure across the rotor. The shearing knife design of the Ingersoll Rand unit could be successful for irregular wood residues like hogged fuel. The larger number of sealing vanes is desireable for a tight system, but results in smaller pockets (except in large sized valves) which could be a disadvantage for coarse wood residues. The "Asthma" feeder of Kamyr may have potential for pressurized gasifiers. The high-pressure steam (or purge gas) could minimize escape of hazardous gases while clearing the valve pocket. The periodic pulse of each discharge of steam and the addition of steam with the feed are unattractive for existing gasifiers.

The Beaumont Rotary Valve, STT Mark II is one of the few rotary valve commercially available that can be operated up to about 11,000 kPa. Available information indicates that the unit has been used to feed a coal gasifier, but no experience has been gained with feeding wood residues. The high- pressure hydrotransport system of Kamyr shows promise for feeding liquefaction processes.

6. Manufacturers

Many companies manufacture rotary feeders. The companies surveyed in this study are:

Aco Sales Engineering Ltd.
B.F. Gump Div., Blaw-Knox Food and Chemical Equipment Co.
Beaumont Feeders Inc.
C.E. Bauer
CEA Simon-Day
Clarke's Sheet Metal Inc.
Construction Machinery Co.
Franklin Miller Inc.
Fuller Co.
General Resources Corp.
Industrial Equipment Co.
Ingersoll-Rand
Kamyr Inc.
Koppers Co. Inc.
Prater Industries Inc.
Premier Pneumatics
Pulva Corp.
Rader Companies Inc.
Semco Inc.
Wm. W. Meyer & Sons Ltd.

L. Rotary Plow Feeder

A rotary plow feeder consists of a horizontal rotating paddle wheel that moves latterally along tracks scraping material from a long slot at the base of a bin (Figure VI-35). The feeder draws material from one point at a time, but because of its motion back and forth along a slot, material is recovered uniformly from the bin. Rotary plow feeders generally discharge material onto other primary feeders and their primary function is as bin unloaders or pre-feeders.

Rotary plow feeders are used in cases where large volumes of materials must be stored and reclaimed. Because of the action of the rotary paddles, these feeders are less prone to hangups. These feeders can operate on unlimited length of travel with variable lateral speed and can handle large capacities. However, this feeder requires high quality design work and special arrangements to avoid spillage. It does not form an airlock and the accuracy of feedrate is limited.

Typically the rotary plow is anywhere from 2 to 4 meters in diameter and can handle material up to 25 to 30 cm in size. No reference to use of this feeder for wood residues has been located. Rise-Louise Corp. manufactures rotary plow feeders which have been successfully applied in handling coal, iron-ore, limestone and other minerals.

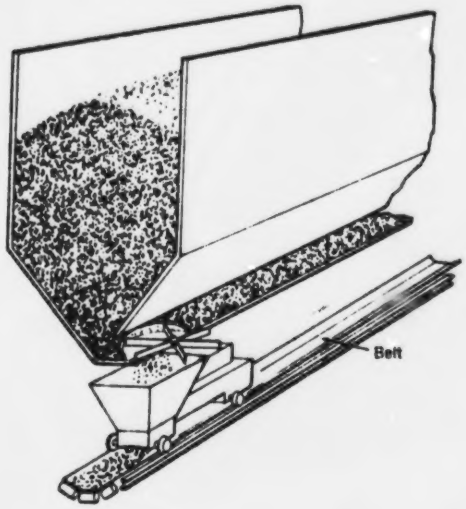


FIGURE VI-35 ROTARY PLOW FEEDER

M. Rotary Table Feeder

Rotary table feeders consist of circular plates rotating under conical bins (Figure VI-36). Material is forced by gravity from the bin onto the table. A vertically adjustable feed collar located immediately above the table is used to control the amount of material which flows from the bin. A plow is located above the table, outside the bin, and plows material which has flowed onto the table into primary feeders or feed chutes. Feed rates may also be controlled by the table's rotational speed.

Rotary table feeders may have capacities as high as 280 tonnes per hour although for handling wood chips these units are generally much smaller. Power requirements are dependent on capacity, table speed, and diameter material characteristics and service anad are shown in Figure VI-37 as a function of capacity.

Rotary table feeders are generally used for bin discharges of material up to minus 5 cm and are often used for feeding wood as pre-feeders to a primary feeder which discharges into the conversion unit.

Two companies have been located which can supply rotary table feeders. These are FMC Corp. which handles smaller sizes of these feeders, up to approximately 20 tonnes per hour and Stephens Adamson Division of Allis-Chalmers which can supply larger feeders, up to 280 tonnes per hour.

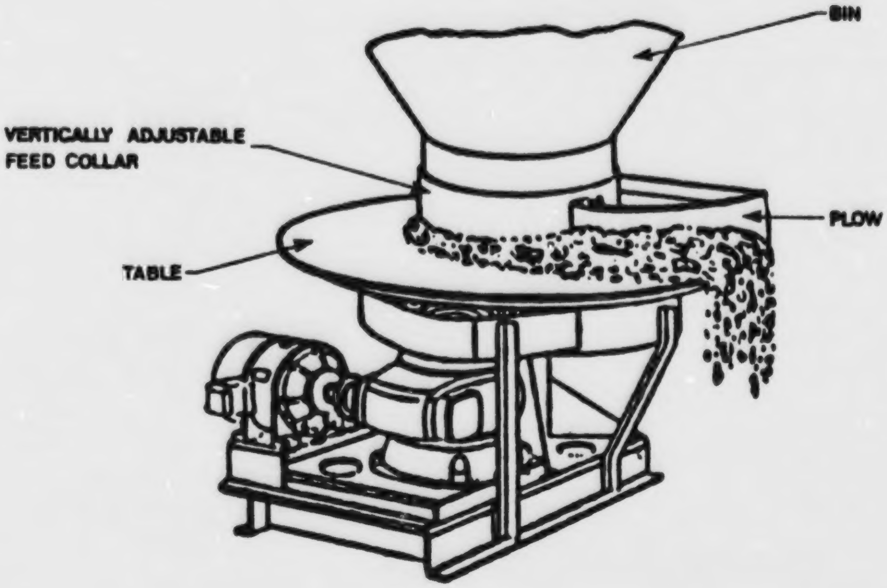

BIN
VERTICALLY ADJUSTABLE FEED COLLAR
PLOW
TABLE

FIGURE VI-36 ROTARY TABLE FEEDER

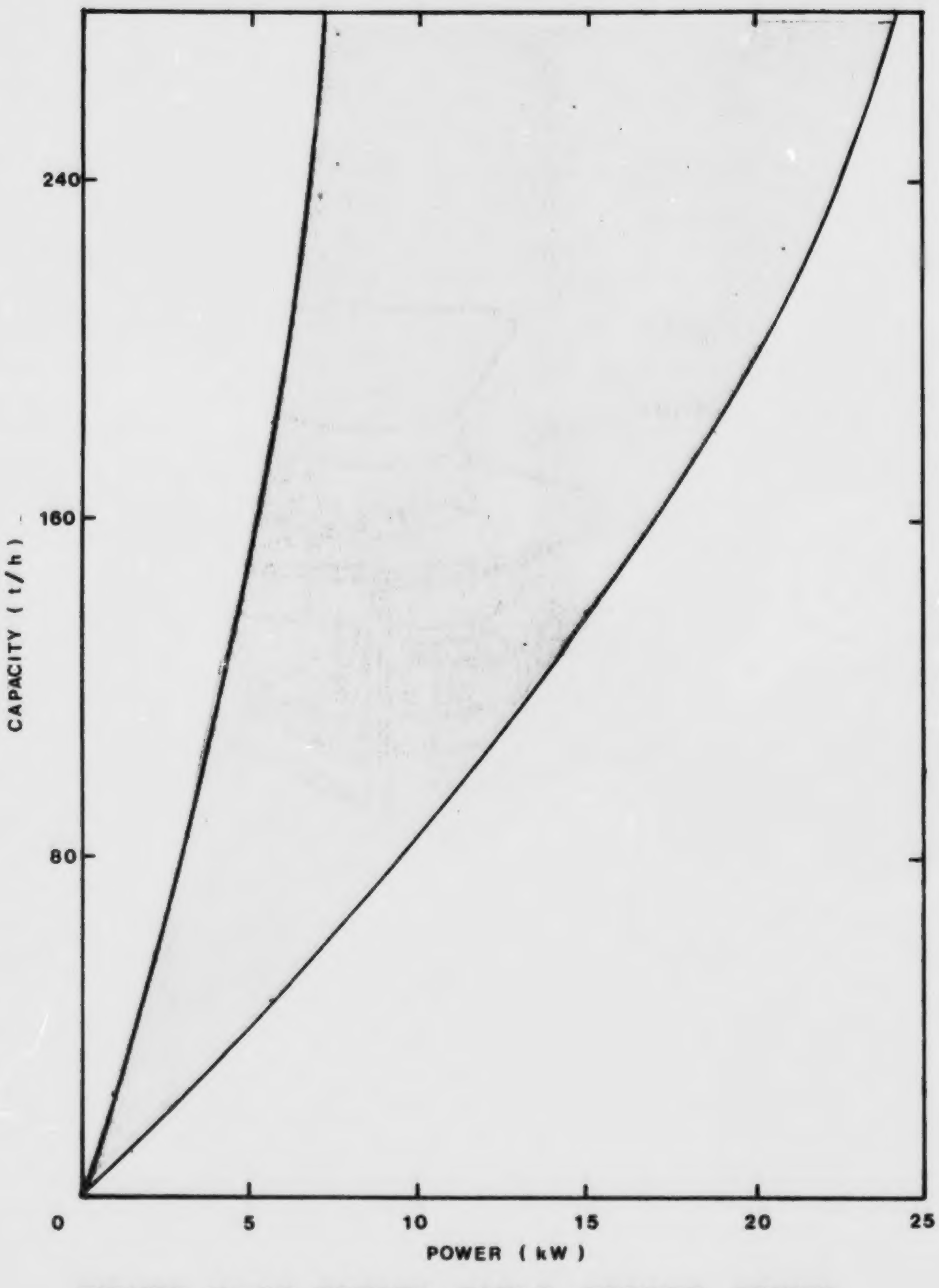


FIGURE VI-37 ROTARY TABLE FEEDER POWER REQUIREMENTS

N. Screw Feeder

1. Design and Operating Principle

A screw (or auger) feeder consists of helical flight attached to a rotating shaft usually contained in a tube or trough housing. The rotating flights trap material in the screw threads and advance it by a screwing motion resulting in feedrate regulation on a volume basis. The feed rate is determined by the helix pitch, depth, speed of rotation and percent loading. Screw conveyors may be right hand or left hand thread, enabling material to be moved forward or backward when using one direction of rotation.

Screw feeders may be classified as: constant cross section screws; variable cross section screws; choked screws; multiple screws; and combinations or modifications of these basic classes of screws. Multiple screws may be further subdivided into: non-intermeshing screws; concentric double screws; twin counter-rotating screws or twin co-rotating screws.

It must be understood that much of the equipment referred to in the following discussion are used as typical examples only. Equivalent equipment by other manufacturers listed at the end of this section may be available.

a) Constant Cross Section Screws

In this type of screw the helix and central drive shaft have a constant diameter along the length of the screw. The feedrate is determined by rate of rotation, depth of helix, pitch (distance between helical flight) and percent of trough loading. This design is very common and widely used for many materials. It may be operated horizontally, inclined, or vertically for the selection, installation, and design of screw conveyors is available from the Conveyor Equipment Manufacturers Association (CEMA). A diagram of a typical constant cross section feeder is shown in Figure VI-38; note the variable diameter across the feed inlet to promote uniform withdrawal from the hopper.

b) Variable Cross Section Screws

In this type of screw the diameter of the helix increases or decreases along the length of the screw. The shaft diameter (or root diameter) may be constant or vary in diameter along the length. These tapered screws are

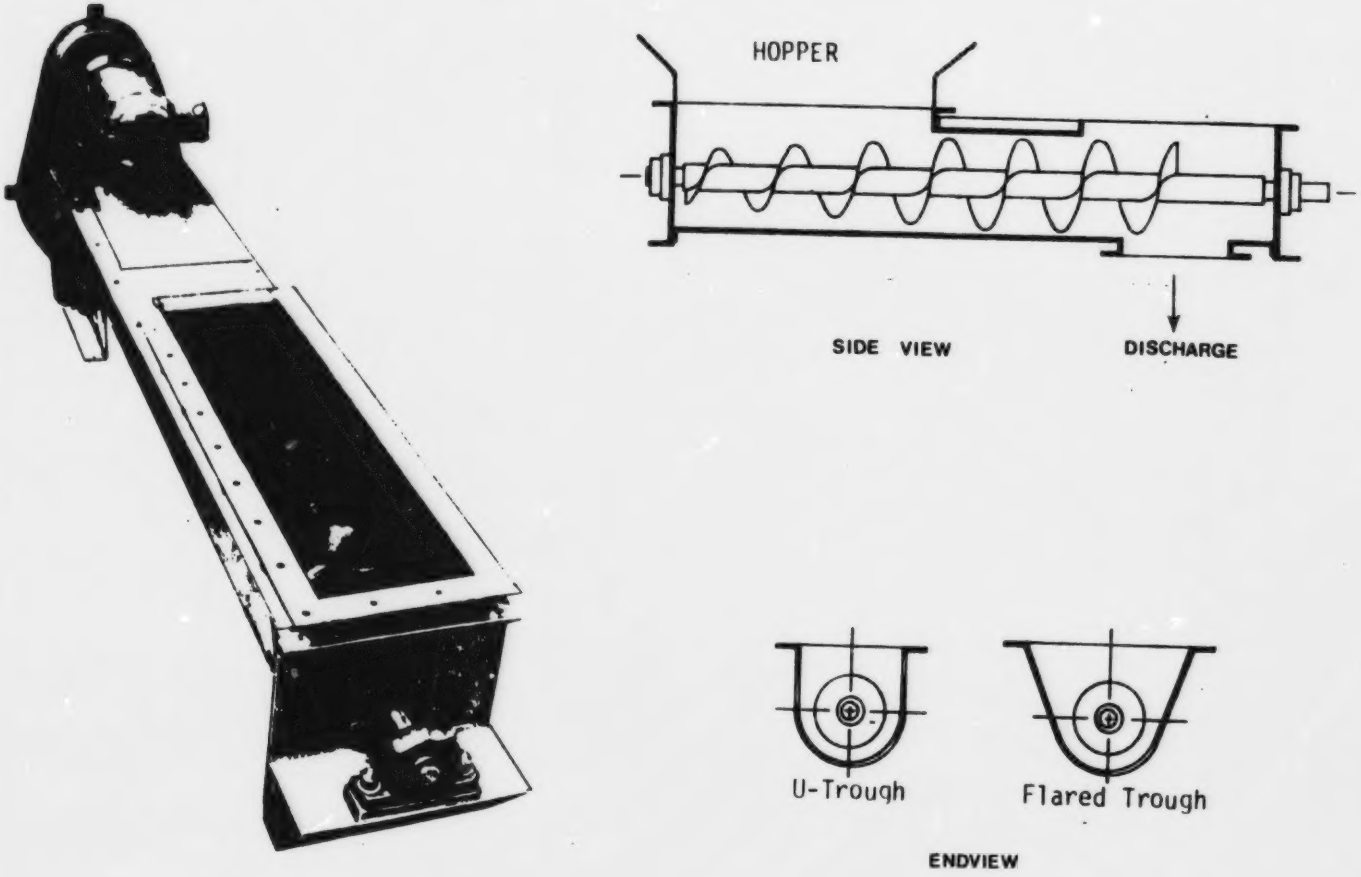

HOPPER
SIDE VIEW
DISCHARGE
U-Trough
Flared Trough
ENDVIEW

FIGURE VI-38 GENERAL PURPOSE SCREW FEEDER

frequently used for pressure applications. A diagram of a typical variable cross section screw is shown in Figure VI-39.

c) Choked Screws

In this design the feed material is discharged against a controllable back pressure provided by some form of choke such as a weighted plate, hydraulically loaded cone, venturi-type constriction or some form of orifice plate. A typical weighted plate choked screw feeder is shown in Figure VI-40. In this design, material is moved from the feeder inlet against the weighted, hinged damper plate by the cantilevered conveying screw. The screw shaft support bearings and the entire drive are mounted on a common sliding based which is free to move longitudinally, resulting in a variable length sealing chamber. During operation, this chamber fills with material because of the forward conveying effect of the screw opposed by the retarding effect of the damper plate.

The entire screw assembly is made to move axially by means of the sliding base and threaded adjusting rod so that the length of the sealing chamber, and hence the material plug, is variable. The counter-pressure of the damper plate is also adjustable by means of a counterweight arm and moveable weight. By varying the length of the material plug and the counter-pressure, a proper seal can be formed which suits the particular requirements of the application.

d) Multiple Screws

Multiple screws may be divided into subgroups.

i) Non-intermeshing Screws

Multiple counter-rotating screws, operating in parallel, feed material without surging and bridging. They are used in live bottom bins because they are bridge-resistant and function as feeders because they are able to distribute material into the receiving vessel in a surge-free manner. A typical multiple screw feeder is shown in Figure VI-41.

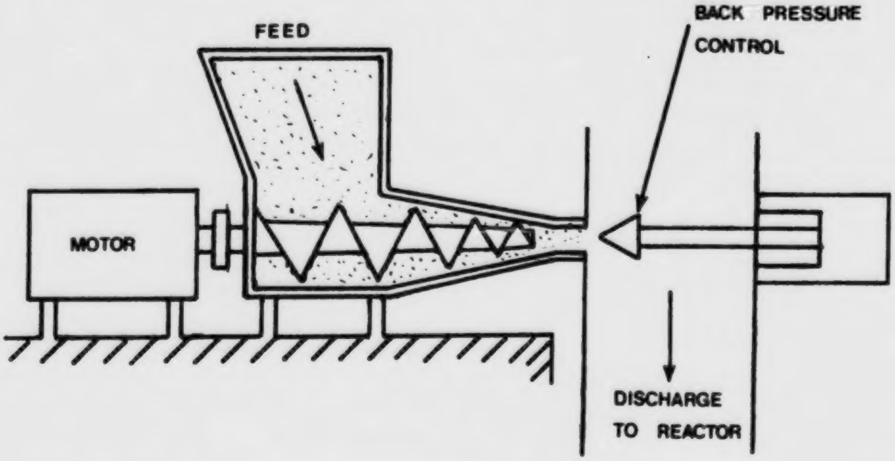

FEED
BACK PRESSURE CONTROL
MOTOR
DISCHARGE TO REACTOR

FIGURE VI-39 VARIABLE CROSS SECTION SCREW FEEDER

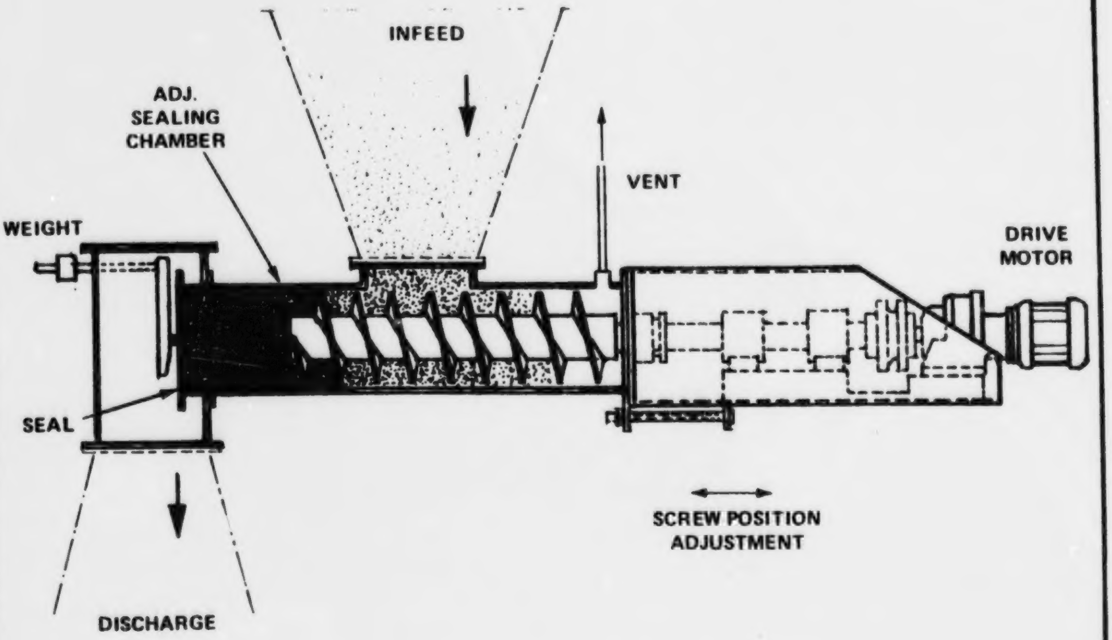

INFEED
ADJ.
SEALING
CHAMBER
VENT
WEIGHT
DRIVE
MOTOR
SEAL
SCREW POSITION
ADJUSTMENT
DISCHARGE

FIGURE VI-40 CHOKED SCREW FEEDER

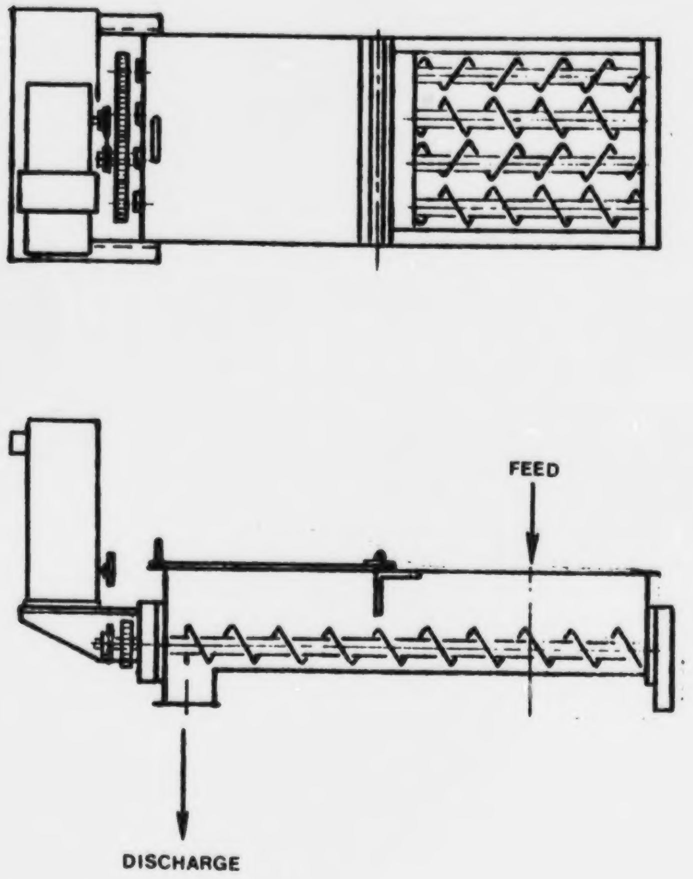

FEED
DISCHARGE

FIGURE VI-41 WYSSMONT MULTIPLE SCREW FEEDER

ii) Concentric Double Screws

In this design (Figure VI-42), a small central metering screw is surrounded by a larger diameter ribbon screw. Both the outer screw and inner screw rotate in the same direction but with the outer screw at a slower rate than the inner screw. The two screws are mechanically geared together rotating in a common precision drive network. By selecting the optimum ratio of speeds between the two screws based on the physical characteristics of a particular product, a constant uniform density of material surrounding the inner metering screw is created and maintained. A reverse helix can be added to the outer screw to ensure proper and accurate density control. The inward radial forces "condition" the feed material and simultaneously fill the metering screw for a full 360 degrees. The motion of the outer screw agitates overlying feed, eliminating possibilities of bridging and hangups. This design feeds volumetrically, resulting in a mass flowrate that depends on material desity. The feed rate is controlled by varying the screw speed.

iii) Twin Counter-Rotating Intermeshing Screws

Bauer markets a patented twin screw device, (Figure VI-43) designed for low- to medium-pressure de-watering or thickening of high-moisture pulps and fibrous slurries. Current applications included fiber slurries in pulp, paper and board mills, fruit and grain residues, and other solid-liquid mixtures in the food, chemical, and oil-seed industries. In the Bauer helipress, intermeshing, counter-rotating twin screws are driven at synchronized speeds by precision-matched spur gears mounted in a sealed, oil lubricated gear case. The self-cleaning screws prevent rotation of plugs of thickened material without the need for resistors or breaker bars. The screws gently compact fibrous material under progressively increasing pressure to express liquids and convey material in a constant, controlled flow. Each series of screw flights is spaced on the shaft to provide compression zones to maintain uniform discharge pressure.

Screens, formed from specially shaped Wedge-Wire bars, encompass 180 degrees of the outer edge of each screw flight and extend the full length of

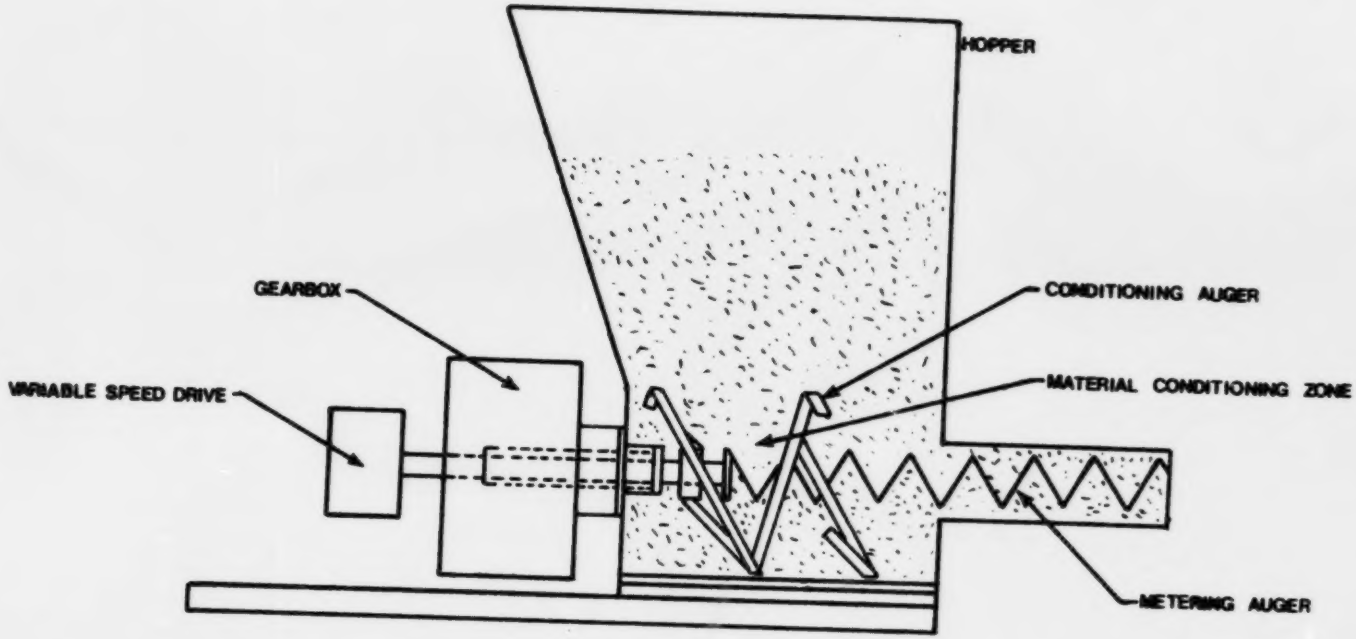

HOPPER
GEARBOX
CONDITIONING AUGER
VARIABLE SPEED DRIVE
MATERIAL CONDITIONING ZONE
METERING AUGER

FIGURE VI-42 ACRISON CONCENTRIC SCREW FEEDER

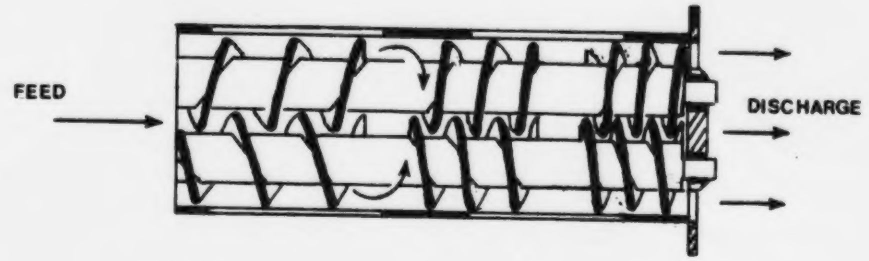

FEED
DISCHARGE

FIGURE VI-43 BAUER HELIPRESS

the screws to provide maximum drainage. A special non-clogging, free draining screen provides maximum open area. This assures a virtually unrestricted flow of fluids from the material being fed or dewatered.

iv) Twin Co-Rotating Intermeshing Screws

This design (Figure VI-44), has two co-rotating, self-wiping screws to convey material through a heated barrel under carefully controlled residence time, pressure and conveyance conditions. The screws fully intermesh with each other creating a self-wiping positive conveying effect without dead spots. The material moves down stream following a figure-eight path by being transferred from one screw to the other after each revolution. Intermittent kneading blocks may be added to screws as required. The Werner and Pfleiderer extrusion system has interchangeable screw and barrel sections that may be arranged to serve a variety of specific process requirements. For example, conditions at different process locations can be varied so that high shear action can be obtained at one location and increased pressure generated at another section. The barrel is constructed from individual units, assembled together to obtain the desired length. Each barrel consists of an upper and lower half section which surrounds a replaceable liner. The twin screw feeder has been used to handle coal, and wood sawdust (wood chips have not been tried).

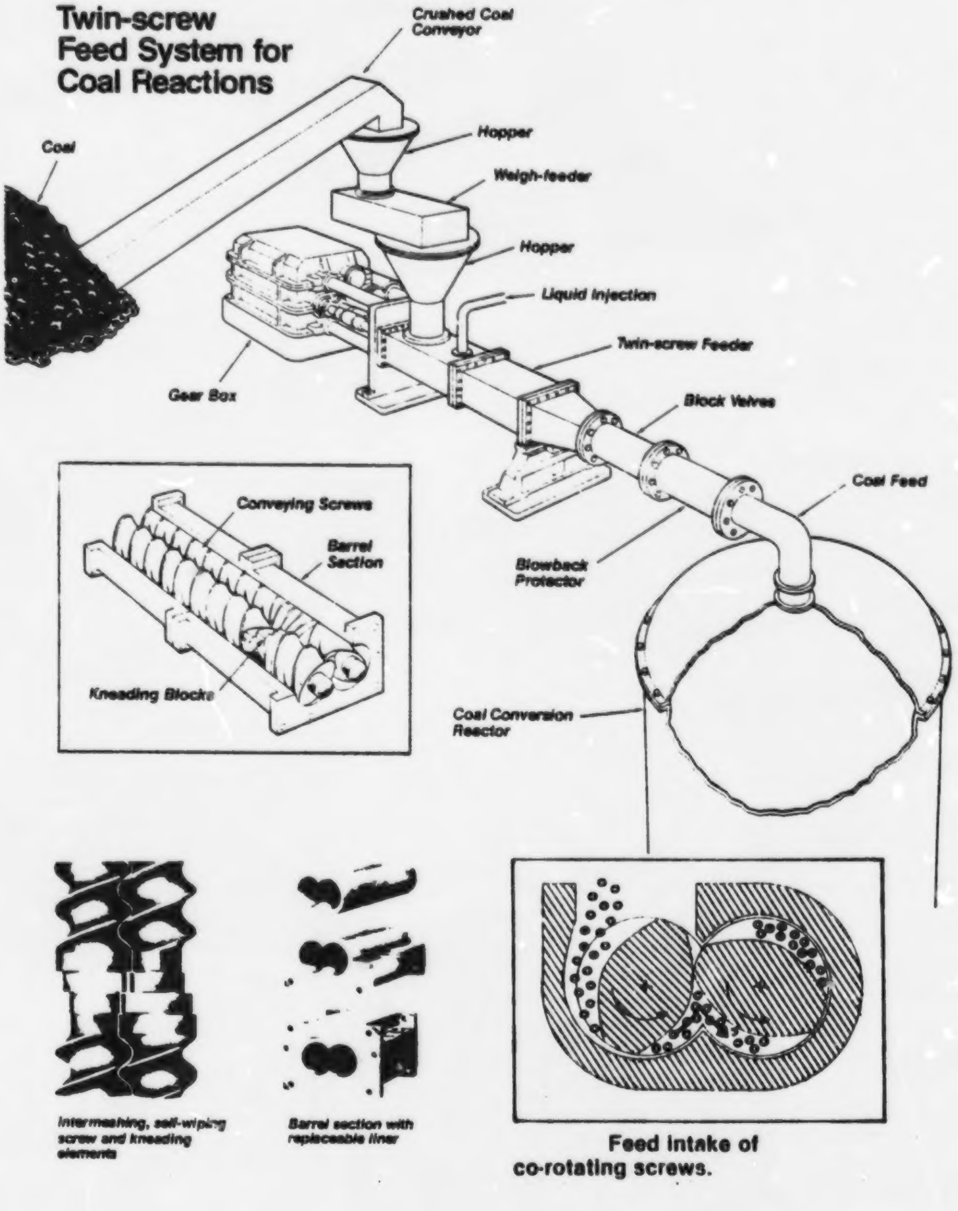
e) Combinations and Modifications of Basic Classes of Screw Feeders

i) Single Screw Underfired Stokers

The underfired stoker used for coal and wood is a well known application of the constant cross section single screw feeder. A typical arrangement is shown in Figure VI-45.

ii) Single Screw Air Lock Feeder

The Fuller-Kinyon feeder (Figure VI-46), is a constant cross section variable pitch screw feeding into a pressurized pneumatic conveyor through a check value. The screw rotates at a relatively high speed (570 rpm or more).


Twin-screw Feed System for Coal Reactions
Crushed Coal Conveyor
Coal
Hopper
Weigh-feeder
Hopper
Liquid Injection
Twin-screw Feeder
Gear Box
Block Valves
Coal Feed
Conveying Screws
Barrel Section
Kneading Blocks
Blowback Protector
Coal Conversion Reactor

Intermeshing, self-wiping screw and kneading elements

Barrel section with replaceable liner

Feed intake of co-rotating screws.

FIGURE VI-44 WERNER & PFLEIDERER FEEDER

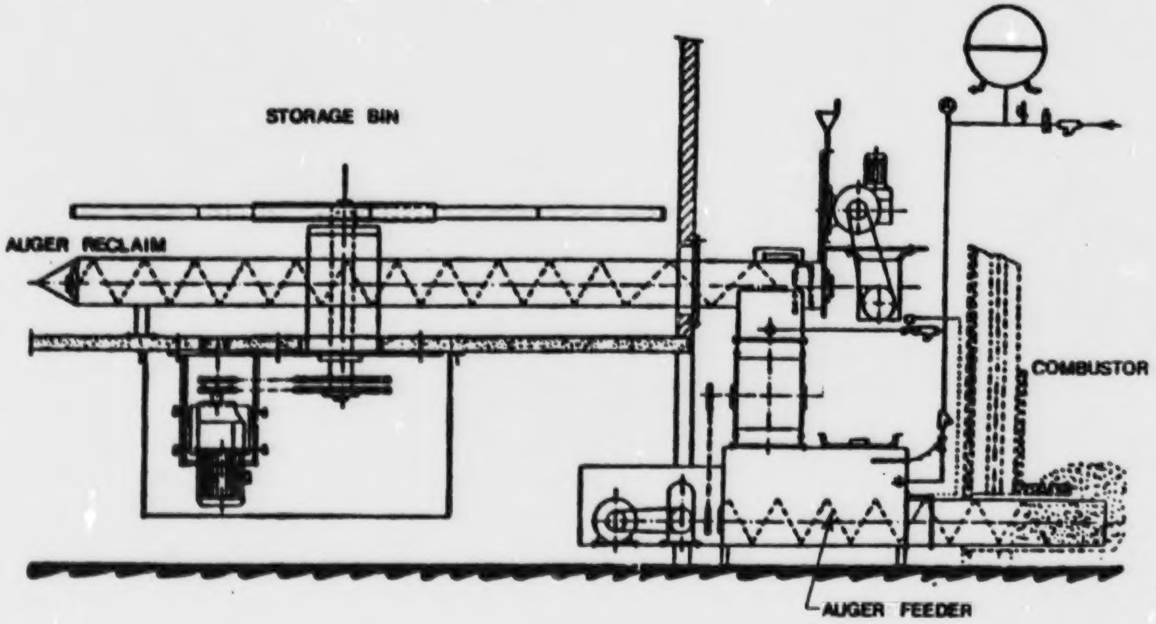

STORAGE BIN
AUGER RECLAIM
COMBUSTOR
AUGER FEEDER

FIGURE VI-45 ARGUSFYR UNDERFIRE SCREW FEEDER

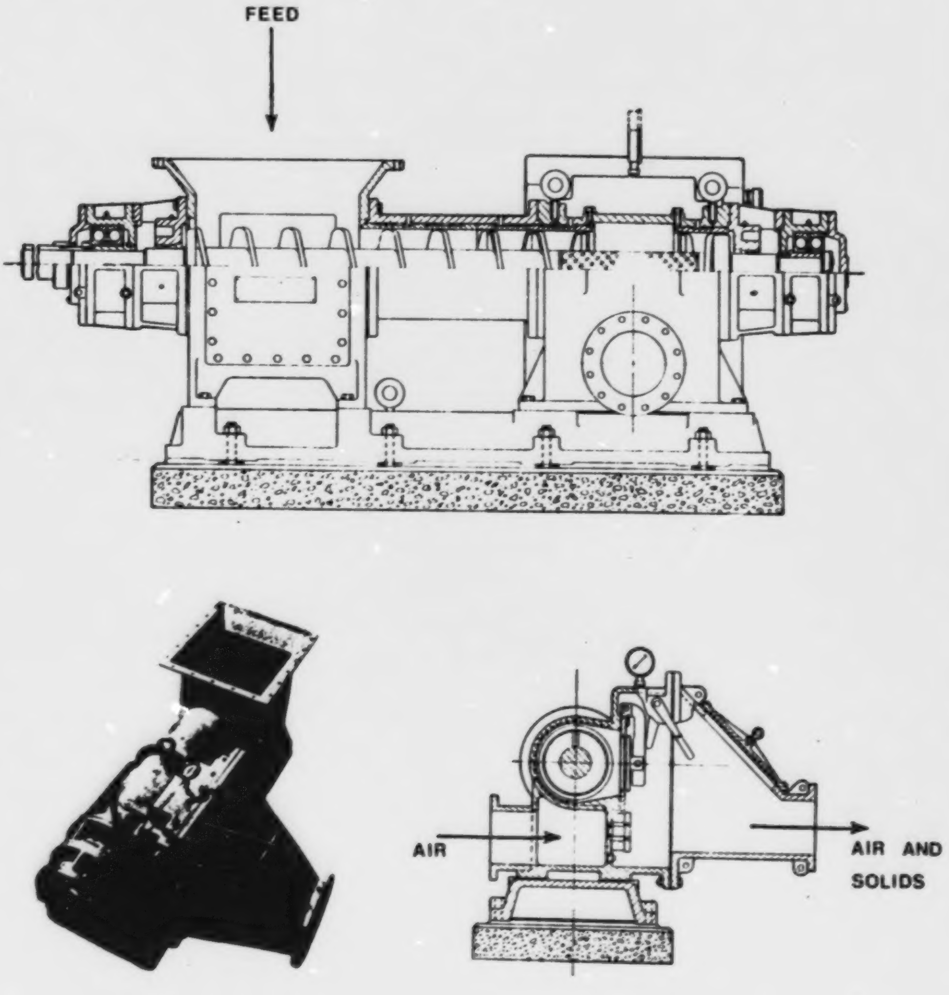

FEED
AIR
AIR AND SOLIDS

FIGURE VI-46 FULLER-KINYON FEEDER

The pump assembly is mounted on a cast iron base. Materials to be conveyed enter the hopper by gravity and are advanced through the barrel by the impeller screw, which is driven through a flexible coupling connection or v-belt drive to the driving motor.

The material is compacted as it is advanced through the barrel by the impeller screw. Its density is further increased in the space between the terminal flight of the impeller screw and the face of the non-return valve to form a seal against the transport line pressure.

The material then enters the mixing chamber, is fluidized by compressed air introduced through a series of air-jets, and is conveyed into the transport line. A catch basin for tramp material, located beneath the hopper, is accessible through clean-out doors located on each side of the pump.

In normal applications, the materials conveyed are dry, pulverized and free-flowing and have a fineness of at least 100% passing 50 mesh, and 60% passing 200 mesh. The Fuller-Kinyon pump has operated with such materials at differential pressure up to 345 kPa. It is available in 7 sizes with capacities ranging from 8 to 200 tonnes per hour (in terms of Portland Cement).

iii) Plug Screw Feeder

In a Plug Screw feeder, a single screw is used to produce a plug of input material (such as coal or wood) in a sealing section at the discharge end of the screw. This moving plug seal prevents back flow of gases from a pressurized reactor. The sealing section may have several different configurations such as a straight pipe with divergent outlet, a convergent-divergent throat (venturi), etc. These designs for the sealing sections have evolved to promote formation of the plug seal and steady flow of material through the sealing zone.

The 100 mm Fuller-Kinyon feeder has been modified (Figure VI-47) for feeding coal into pressurized vessels (Feild). The unit used for these tests is the smallest marketed and has a rated capacity of 7 tonnes per hour for cement. The major

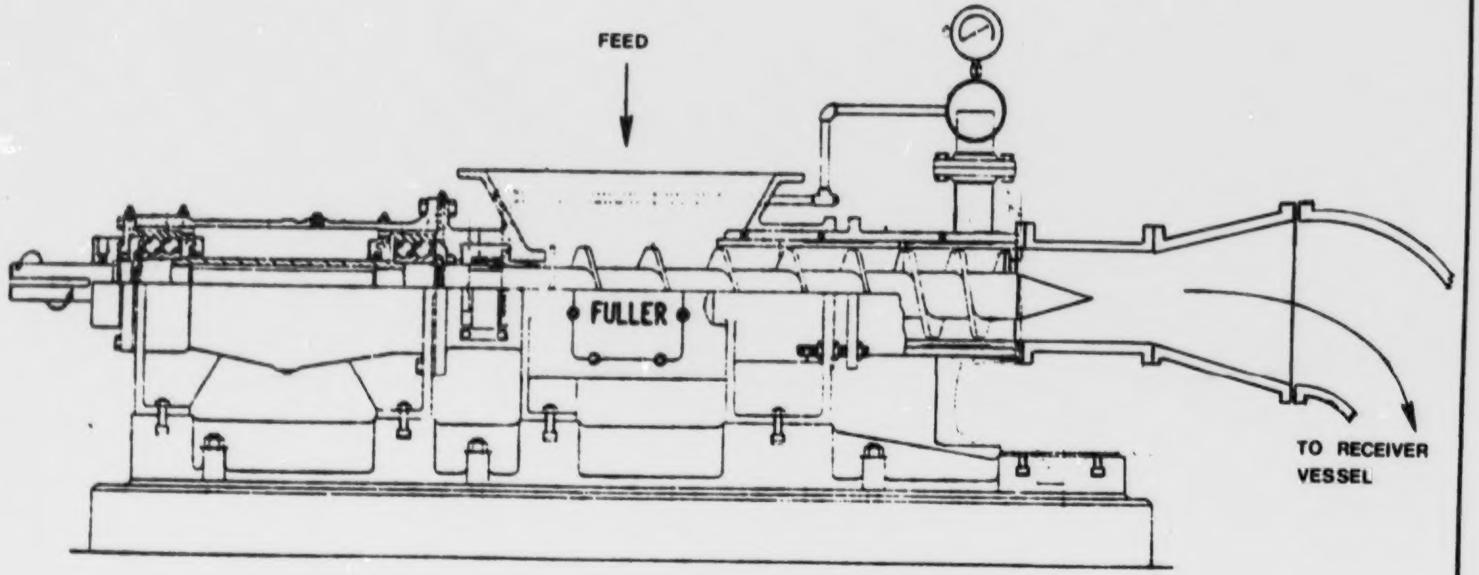

FEED
FULLER
TO RECEIVER
VESSEL

FIGURE VI-47 FULLER-KINYON PUMP MODIFIED FOR PRESSURE FEEDING COAL

modifications were: 1) removal of check valve, mixing chamber and air jets from the output end of the pump; 2) extension of the barrel (with various configurations) beyond the terminal flight of the screw to provide additional length of extruded material for sealing purposes; and 3) addition of a cone on the discharge end of the screw to prevent a void in the extruded material. Using minus 6 mm coal, a screw rotation speed of 570 rpm, a 23 cm straight seal tube followed by divergent truncated cone, (giving overall seal length of 48 cm) resulted in a constant throughput of about 8 tonnes per hour coal at a pressure differential of 620 kPa with no blowback. For this condition 25 kW was required. Because of limited drive horsepower available (30 kW), most successful operations were limited to seals of 25 cm or less and differential pressures of 413 kPa or less.

The Koppers Company Inc. (Sprout Waldron Division) Plug Screw Feeder is commercially available and operates in a manner similar to the modified Fuller-Kinyon feeder in that wood chips form a plug in a tapered spool prior to injection into a pressurized steaming vessel. The tapered spool can be considered as a venturi consisting of a converging screw rotating in a converging housing to form a plug at the venturi throat. The throat is followed by a diverging section about 30 cm long. A conical choke is located at the outlet of the divergent section but is operated normally open. The choke is closed if the plug is lost. The feeder can feed into a vessel at a differential pressure of 1,380 kPa, although 1,034 kPa is typical.

The General Electric company has also developed an extrusion plug screw feeder which is installed on their operating GEGAS-"D" coal gasifier. It is comparable to the Fuller-Kinyon plug screw in that a straight seal section follows the injection screw. It also has a chopper inside the pressure vessel to break up the extrudate from the feeder.

iv) Variable Section Screw with Metering Tube

In this combination a variable speed variable cross section screw delivers wood chips to a tubular metering section. The feedrate is controlled by the rate of rotation of the screws. A diagram of this design is shown in Figure VI-48.

v) Conical Feeder With De-watering Cage

While designed for high pressure de-watering of pulps, and medium- to high-moisture fibrous material, the Bauer Pressafiner (Figure VI-49) may be considered to be a feeder. A trunacated conical feed screw provides initial compression and eliminates voids. The compressed material is moved over a unique screen which extends the full length of the feed worm. A patented design of collar provides a fiberizing action to soften separate fibres. The action facilitates further processing because it creates more surface for reaction. The long feed screw forms a plug to seal against back pressure from the pressurized reaction.

vi) Constant Section Screw With Reciprocating Piston

Stake Techology has developed a "Co-Axial Feeder" in which feed material is metered to a single compression screw and the precompacted "plug" is moved forward against a choke by a reciprocating piston (Figure VI-50). A screw conveyor is arranged to pre-compact loose wood residues and pass them to an intermediate chamber. Following the intermediate chamber, a piston reciprocating coaxially with the screw conveyor forces the material under high pressure in a direction coaxial with the centerline of the screw conveyor and through a choker. The reciprocating piston has an annular face, whose diameter is generally the same as that of the conduit. A high degree of compactness is achieved primarily by the action of the piston. Accordingly, the mounting of the screw conveyor is not subjected to extreme forces.

Using this feeder, wood sawdust, and bark pieces up to 5 cm square by 0.6 cm thick have been fed to pressurized vessels across differential pressures of up to 5,515 kPa, although most service has been at a pressure of 2,413 kPa.

vii) Constant Section Reciprocating Screw

A reciprocating screw-piston feeder has been demonstrated on a pilot scale by Ingersoll-Rand to

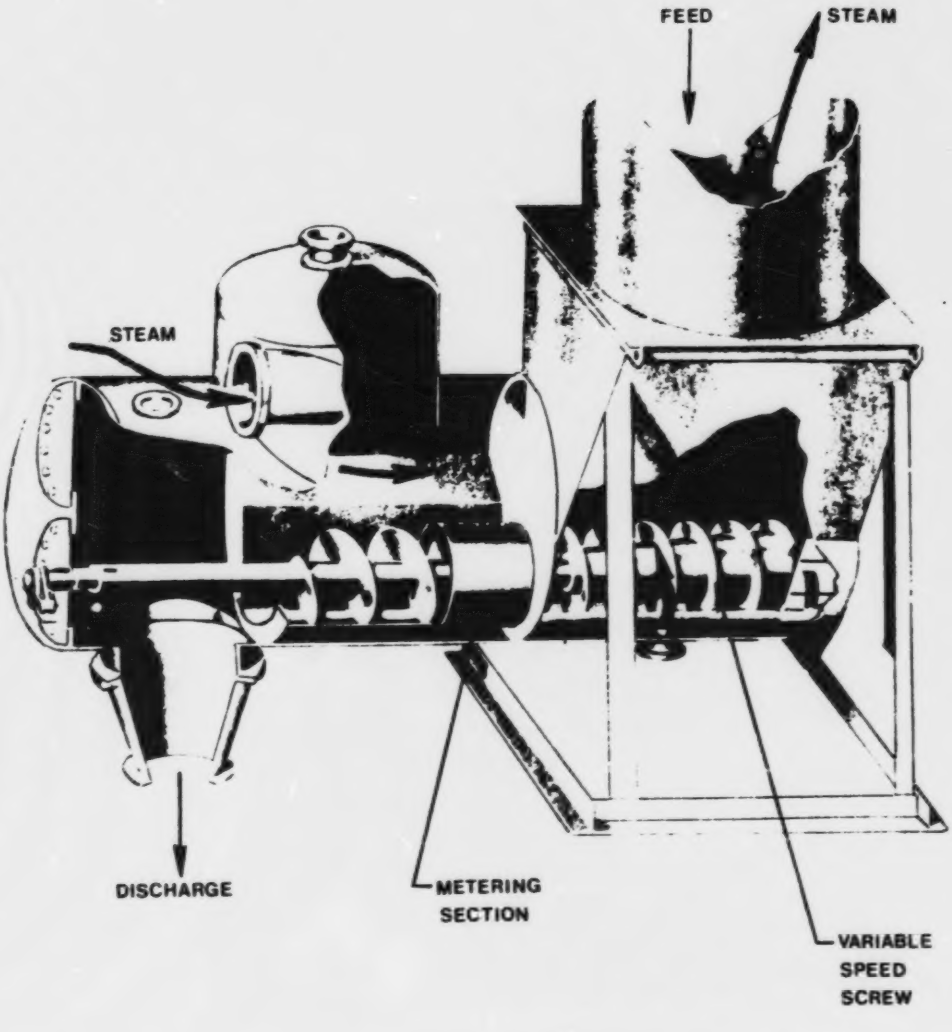

FEED
STEAM
STEAM
DISCHARGE
METERING SECTION
VARIABLE SPEED SCREW

FIGURE VI-48 BAUER FEEDER PRESTEAMER

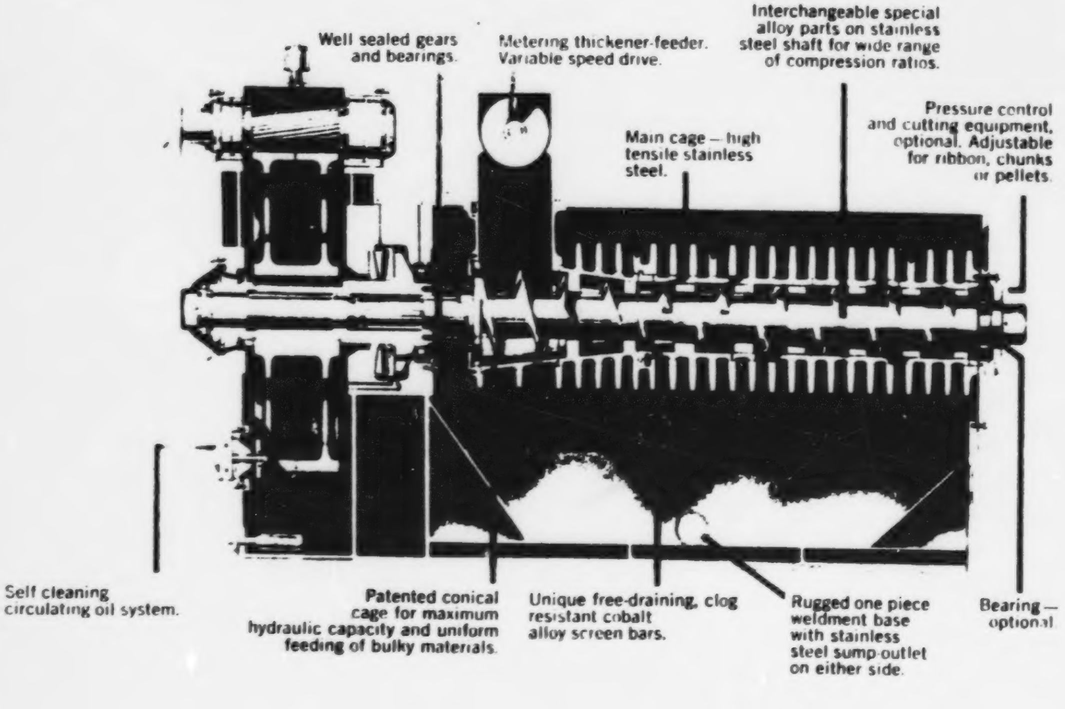

Well sealed gears and bearings.
Metering thickener-feeder. Variable speed drive.
Interchangeable special alloy parts on stainless steel shaft for wide range of compression ratios.
Main cage — high tensile stainless steel.
Pressure control and cutting equipment, optional. Adjustable for ribbon, chunks or pellets.
Self cleaning circulating oil system.
Patented conical cage for maximum hydraulic capacity and uniform feeding of bulky materials.
Unique free-draining, clog resistant cobalt alloy screen bars.
Rugged one piece weldment base with stainless steel sump outlet on either side.
Bearing — optional

FIGURE VI-49 BAUER PRESSAFINER

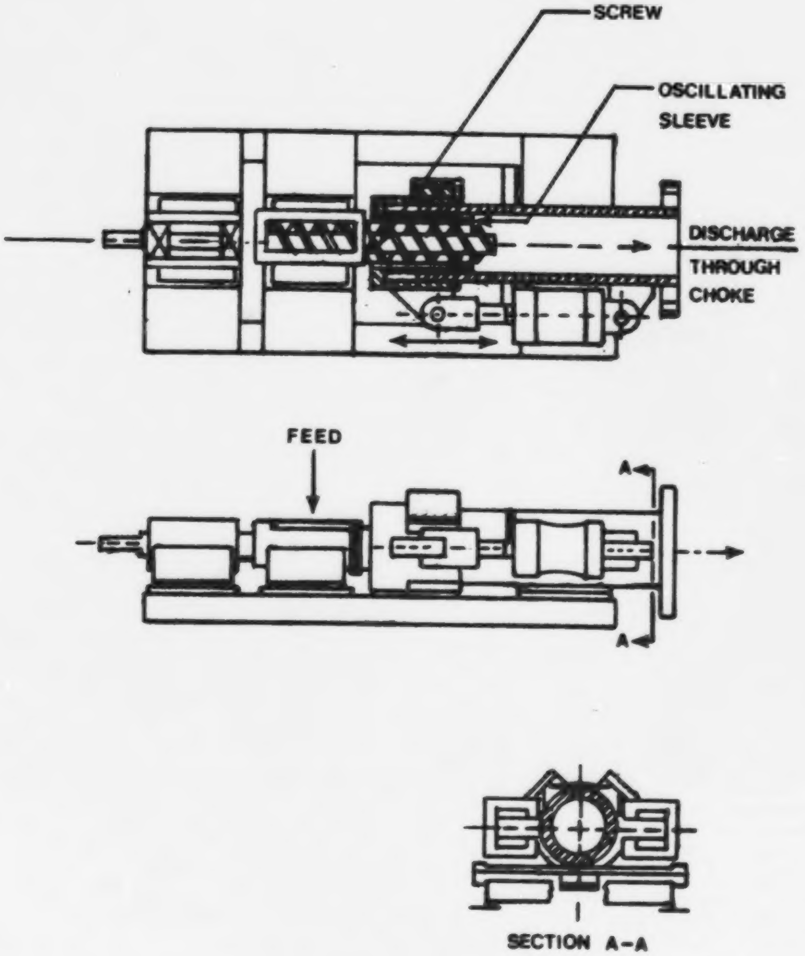

SCREW
OSCILLATING SLEEVE
DISCHARGE THROUGH CHOKE
FEED
A
A
SECTION A-A

FIGURE VI-50 STAKE TECHNOLOGY FEEDER

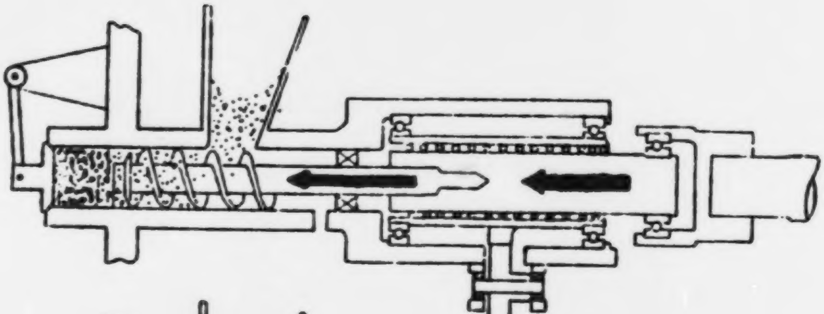
work well as a dry coal feeder. A diagram of this combination feeder is shown in Figure VI-51.

Coal is gravity fed to the screw from a hopper, and as the screw is rotated, the coal particles are conveyed along the barrel to the injection section. The axial thrust force on the screw causes the screw to retract. This is the backfill portion of the cycle. Once the screw is fully retracted, the screw rotation stops and injection begins. In the first portion of injection cycle the coal in the injection section is highly compacted forming a coal plug. Once the coal is compacted and the friction between the coal plug and the barrel is overcome by the injection force, the coal plug is delivered from the discharge end of the barrel. The injection is then stopped at a pre-selected injection pressure (force) on the coal of about 44,800 kPa. During operation, the minimum plug length may vary as much as 2.5 cm, however, the maximum plug length remains constant. The compaction of the coal plug is maintained at a high enough level to provide a seal against discharge gas back pressure.

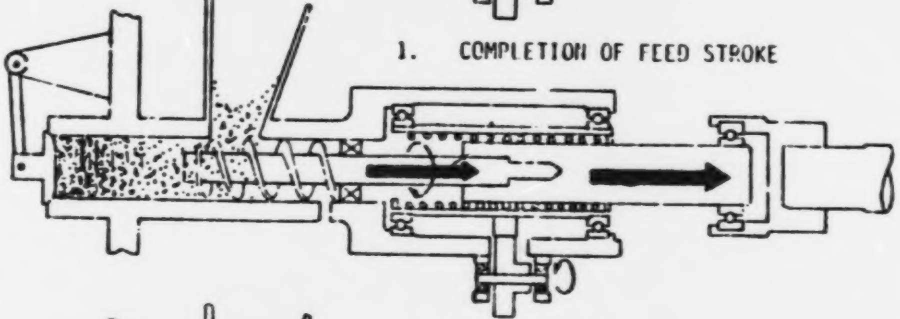
The 14 cm diameter dry coal screw feeder machine, developed by Ingersoll-Rand Research is comprised of a modified version of the injection unit of a standard production model IMPCO #1500 Breechlock Plastic Injection Molding Machine fabricated by the former IMPCO plastic division of the Ingersoll-Rand Company.

All functions in the machine are performed hydraulically. Four hydraulic pumps (total 14.9 l/s capacity), powered by two 75 kW electric motors, provide the required hydraulic power. The injector assembly is mounted on the base assembly in such a way that it can be moved forward and backward along the screw axis with hydraulic cylinders. The machine is designed for automatic injection mode operation.

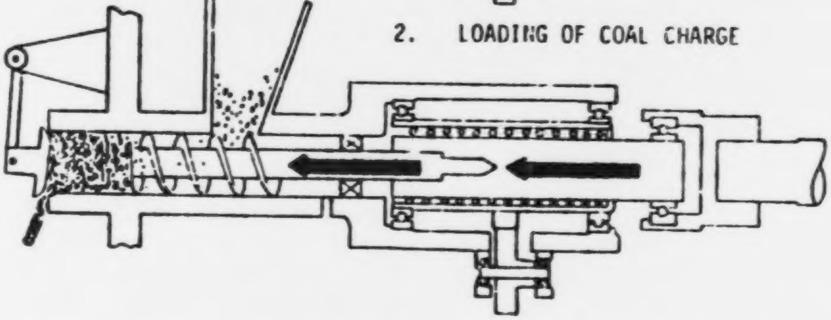
The screw is rotated by a co-axial, multivane, high torque, low speed, hydraulic motor. The motor maximum torque capacity is 1,016 Nm. The screw speed is continuously variable from 0 to 117 rpm and is independent of the load. The screw is made up of AISI 4140 steel heat treated to an Rc-38 hardness level. The outside diameter of the flights is



1. COMPLETION OF FEED STROKE



2. LOADING OF COAL CHARGE



3. FEED STROKE

FIGURE VI-51 INGERSOLL-RAND RECIPROCATING SCREW PLUG FEEDER

inlaid with hardface material. All the other screw surfaces are chrome plated. The screw pitch and flight width are 14 cm and 13 mm respectively. Channel depths of 2.1 and 3.1 cm were tested. The screw is designed with a 2.5 cm diameter internal, longitudinal hole which is used to circulate cooling water to the screw discharge end.

The barrel consists of an Xaloy 101 liner (base material 4340 steel) shrink-fitted to an outer 4142 steel sleeve. The liner is specially machined to provide a helical path to permit cooling water to pass between the outer sleeve and the liner.

To meet coal size requirements of minus 5 cm with minimum fine, a special extrudate breaker was developed. It consists of a static edge type breaker housed in a pressure receiver.

As a result of testing and about 200 hours of operation on coal, Ingersoll-Rand Research feels the screw piston feeder is widely applicable and plans to demonstrate performance with other feed materials.

2. Performance Characteristics And Costs

Performance characteristics of Screw feeders are summarized in Table VI-12, using the following classifications:

Constant Cross Section Screws

Variable Cross Section Screws

Choked Screws

Multiple Screws

- non-intermeshing
- concentric double
- twin counter-rotating intermeshing
- twin co-rotating intermeshing
- combination and modifications of basic classes of screw feeders

Characteristics such as function, feed material, feed size range, capacity range, differential pressure, status of development and developer/manufacturer are tabulated. Volumetric capacity data has been converted to a weight basis of

TABLE VI-12

Characteristics of Screw Feeders

Manufacturer/ Developer	Size (mm)	Feed Material	Feed Size (mm)	Capacity Range (t/h	Differential Pressure (kPa)	Status and Comments
CONSTANT CROSS SECTION:						
General Fabricators		many		wide	0	-Widely available
		-fine	<3.3			
		-granular	<175			
		-lumpy	<400			
		-irregular	fibrous cylindrical			
		free flow to sluggish and abrasive				
		wood chips	< 75	up to 150		
		coal	< 75	up to 350		
VARIABLE CROSS SECTION:						
Sunds Defibrator Ltd.	337	wood chips	50	9.45	275	-Commerically available
	400	wood chips	50	22.80	275	-Meters -De-waters
	425	bark (proposed)	50	4.5	275	-No experience on bark, hog, or sawdust. Sawdust may plug drain holes
CHOKED:						
Rise Louise Corp.	100	coal, ore,	< 75	0.38	49.8	-Commercially available
	250	etc.		2.27		
	400	wood chips		5.41		
	600			10.57		

TABLE VI-12 (continued)

Characteristics of Screw Feeders

Manufacturer/ Developer	Size (mm)	Feed Material	Feed Size (mm)	Capacity Range (t/h	Differential Pressure (kPa)	Status and Comments
MULTIPLE:						
-Non-Intermeshing Counter-Rotating						
Wyssmont Comp. Inc. Miller Hofft Inc.		coal sticky solids	N/A	to 54.4	0	-Commercially available -Meters, distributes
-Concentric Double Screws						
Acrison, Inc. Metal Fab., Inc.		many wood chips	<75	many 1.81 4.54 30.8	0	-Commercially available -Meters
-Twin Counter-Rotating Intermeshing						
C.E. Bauer "Helipress"		pulp, fibres, fruit, grain	N/A	N/A	N/A	-Was commercially available - discontinued -Meters, de-waters

TABLE VI-12 (continued)

Characteristics of Screw Feeders

Manufacturer/ Developer	Size (mm)	Feed Material	Feed Size (mm)	Capacity Range (t/h	Differential Pressure (kPa)	Status and Comments
-Twin Co-Rotating Intermeshing						
Werner & Pfleiderer Corp.	57	coal	12 (typical) 37 (max.)	0.45	10,340 (typical) 20,680 (max.)	-Commercially available -Meters
	90					
	120					
	130					
	180					
	240					
	300			22.7		
	53	sawdust		0.1	10,340 (typical) 20,680 (max.)	-No experience on bark or chips
COMBINATIONS AND MODIFICATIONS:						
-Underfire Stoker						
Will-Burt Co.		coal		0.19	0	-Commercially available -Meters
Worley Equipment				0.28		
Sorenson Energy				0.33		
Sorenson Energy Will-Burt Co.		wood pellets		0.9 (est)	0	-Tried successfully

TABLE VI-12 (continued)

Characteristics of Screw Feeders

Manufacturer/ Developer	Size (mm)	Feed Material	Feed Size (mm)	Capacity Range (t/h	Differential Pressure (kPa)	Status and Comments
-Single Screw Airlock						
Gatx-Fuller Co. Fuller-Kinyon Pump, Type M		dry pulverized free-flow cement coal	100% <0.30 75% <0.150 45% <0.045			-Commercially available -Meters, distributes
	100 125 200 250 300			4.08 8.16	345	
-Plug Screw						
Koppers Company Inc. Sprout Waldron Div.	225	wood chips	12 - 50	5.35	1,034 (typical) 1,379 (max.)	-Commercially available -Meters
	300	wood chips	12 - 50	25.40	1,034 (typical) 1,379 (max.)	
Gard, Inc.	100	lump coal	6.3 - 9.5	8.18	414 (typical) 621 (max.)	-Proof of concept
General Electric Co.	152	coal & tar	3.2	0.91	2,068	-7 hours test time -Has adjustable die seal
-Variable Section Screw With Metering Tube						
C.E. Bauer	150	wood chips	12 - 50	7.5	0	-Commercially available -Meters -Presteams

TABLE VI-12 (continued)

Characteristics of Screw Feeders

Manufacturer/ Developer	Size (mm)	Feed Material	Feed Size (mm)	Capacity Range (t/h	Differential Pressure (kPa)	Status and Comments
-Conical Feeder With De-Watering Cage						
C.E. Bauer "Pressafiner"	165 216 216 343 254 343	oil seed, slurries, pulps, agri-residue wood chips	12 - 50	2.72 5.44 9.80 17.96 20.68 41.91	up to 68,950	-Commercially available -Meters, de-waters
-Constant Cross Section With Reciprocating Piston						
Stake Technology Ltd. "Co-Axial Feeder"		-straw -bagasse -wood powder -whole tree chips -bark -dry to 70% moisture	50.8 X 6.3		2,413 (typical) 5,515 (max.)	-Commercially available -New technology -Meters -Potential to de-water
	40	wood, sawdust	9.5	6.8	3,102	
	50	wood powder chips, sawdust	0.60	9 - 22.7 45.4	low pressure	

TABLE VI-12 (continued)

Characteristics of Screw Feeders

Manufacturer/ Developer	Size (mm)	Feed Material	Feed Size (mm)	Capacity Range (t/h	Differential Pressure (kPa)	Status and Comments
-Constant Section, Reciprocating Screw						
Ingersoll-Rand Research Inc.	140	dry coal	3.17 25.4	1.43 1.82	5,170 (typical) 10,341 (max.)	-Pilot plant -200 hour test operation -Installed on gasifier for verification run -Developer considers widely applicable -Meters

metric tonnes per hour. For wood, all weights are based on a typical density of 320 kg/m^3. For coal, all weights are based on a typical density of 800 kg/m^3. Power requirements in kilowatts have been plotted against capacity and are shown in Figure VI-52.

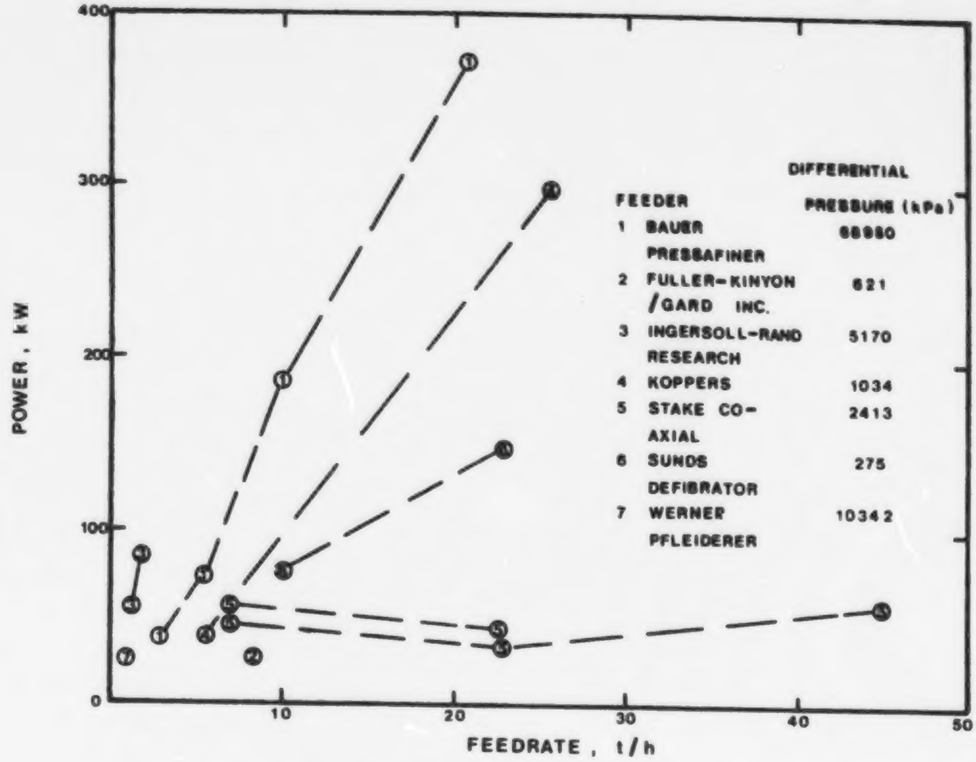
Costs of several classes of screw feeders for several throughput capacities are plotted in Figure VI-53. Costs normally include the metering feeder (if required), the main compression/injection screw, as well as the mechanical drive. Costs are shown in Canadian and U.S. dollars as of late 1981. In the fourth quarter of 1981 the Marshall and Stevens equipment costs index was 736.4. By the use of this index costs for future years can be estimated. It can be seen from the plot of cost versus capacity that generally speaking, equipment capable of feeding into pressures of over about 276 kPa cost about $100,000 or more. Capital and operation cost for the Ingersoll-Rand Research Inc. Retractable Screw Feeder are contained in a Jet Propulsion Laboratory Report "Feeder Evaluation Methodology for Fossil Fuel Processing Division, U.S. Department of Energy", JPL 5030-308, March 1979 which is still under review and not yet released.

3. Guidelines for Proper Use

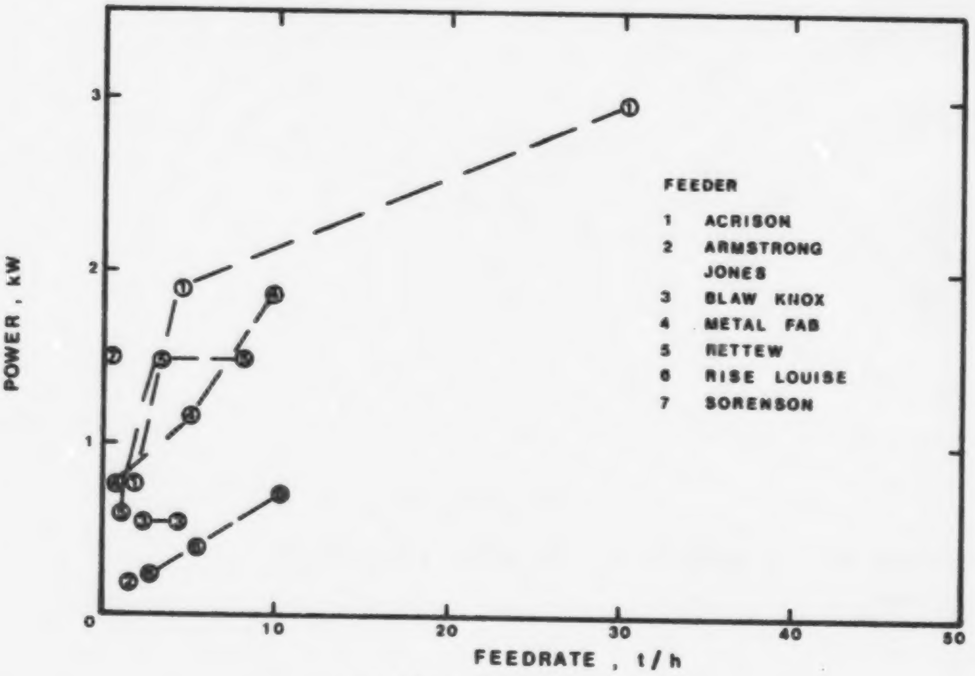
Screw feeders are bulk material transporting devices capable of handling a great variety of materials which have relatively good flowability. Flowability denotes the degree of freedom of individual material particles to move past each other. This characteristic is important as the screw helix rotates with a fixed trough or tube, pushes the material along the bottom and sides, shearing the material in the radial clearance between the helix and trough and causing the material to tumble upon itself as the moving face of the helical flight tends to lift the material.

Screw conveyors are very adaptable to the volumetric control of material flow from the bottoms of bins, hoppers, storage piles and the like. In this use they are termed screw feeders and as such fill a most important place in industry.

In the handling of some material screw feeders lend themselves very well because the enclosing trough can be made tight enough to contain dusts or vapors, thus reducing personnel hazards. Conversely, materials that must be kept free from contaminants may be satisfactorily handled. Screw feeders, particularly the tubular types, can be used effectively as air vapor lock devices. The conveyed solids enter and leave, but the passage of gases or vapors is restricted.



B. PRESSURE FEEDERS



A. LOW-PRESSURE FEEDERS

FIGURE VI-52 POWER REQUIREMENTS OF SCREW FEEDERS

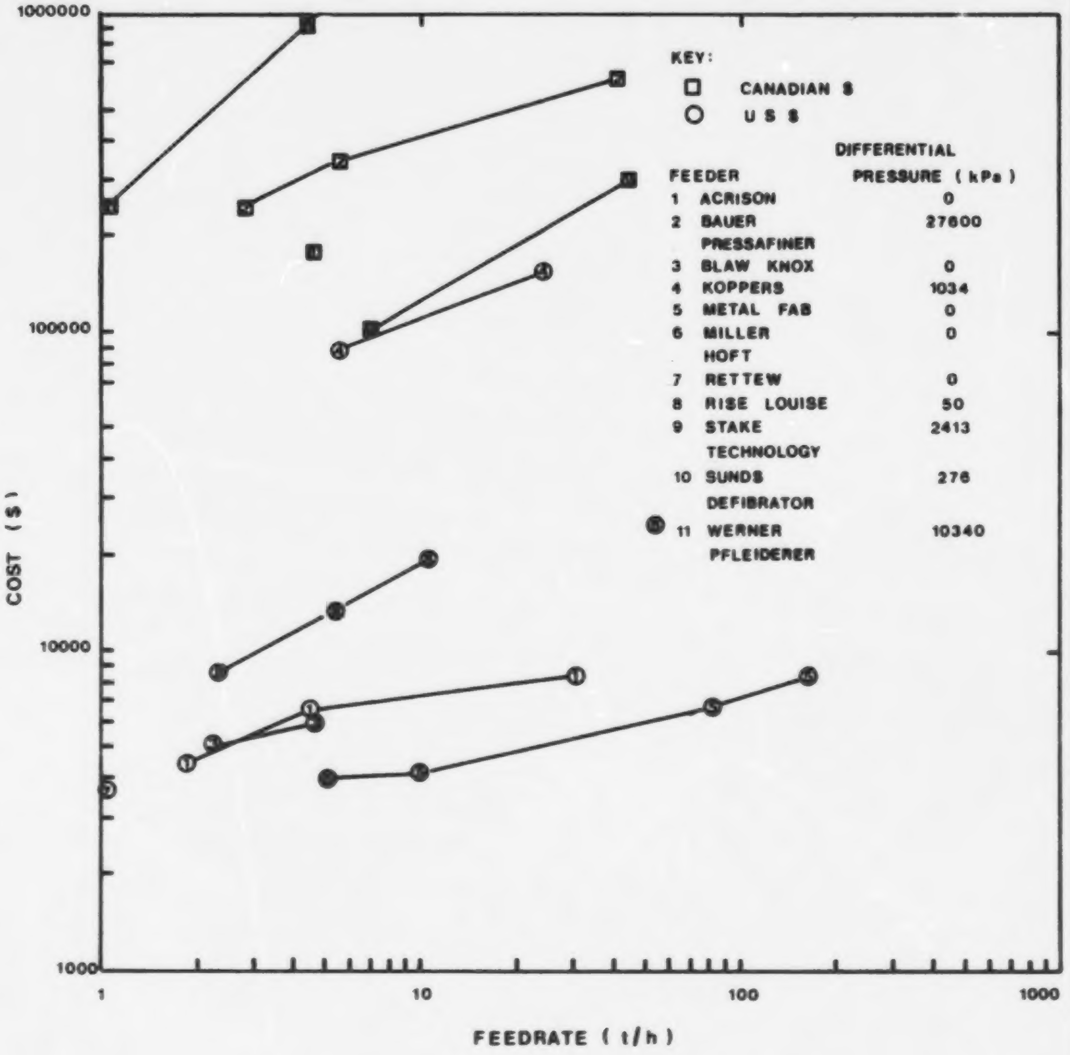


FIGURE VI-53 COSTS OF SCREW FEEDERS

Screw feeders may be operated horizontally or on an incline. Several types of vertical screw conveyors are available.

Screw feeders when properly sized and designed can be used to feed practically any type or size of wood residue, although the most suitable materials are less than 8 cm in size. It is important to size a screw carefully since objects larger than the screw pitch will likely jam and immobilize the screw. Problems of bridging may also be encountered at low feedrates. Use of a vibrating or diaphragm agitator to prevent bridging in feed bins is common.

Auger feed systems are commonly used on many of the newer wood residue combustion system. These feed systems have been plagued by two problems:

-bridging at the inlet to the feeder

-formation of an immobile plug within the feeder thereby stalling the drive system.

Advantages and disadvantages of screw feeders are as follows:

Advantages:
- positive volume discharge, although slightly erratic;
- enclosed design makes feeder dust free and reduces or eliminates air ingress when connected to energy convesion system;
- simple installation and low space requirements;
- arrangement versatility.

Disadvantages:
- vulnerable to jamming by compression and packing of residues;
- poor for fibrous and stringy residues;
- vulnerable to bridging at feeder inlet;
- trough wear is a problem with abrasive (sand laden) residues

4. Applications

A distinguishing characteristic of the screw feeders identified during the survey of manufacturers was the ability or inability of the unit to feed against a differential pressure. The following discussion presents information on the classes of feeders categorized into (a) non-pressurized and low-pressure feeders and (b) pressurized feeders. The units included in the section on non-pressurized and low-pressure feeders are only suitable for this application, although this does not mean pressurized feeders could not be applied equally well in some cases. The grouping of the feeders is as follows:

Non-pressurized and low-pressure feeders:

- -Constant Cross Section Screw;
- -Choked Screw Feeder;
- -Multiple Non-Intermeshing Screws;
- -Concentric Double Screws;
- -Single Screw Underfire Stoker;
- -Variable Section Screw with Metering Tube.

Pressurized feeders:

- -Variable Cross Section
- -Twin Counter-Rotating Intermeshing Screws
- -Twin Co-Rotating Intermeshing Screws
- -Single Screw Air Lock Feeder
- -Plug Screw Feeder
- -Conical Feeder with De-Watering Cage
- -Constant Section Screw with Reciprocating Piston
- -Constant Section Reciprocating Screw

a) Non-Pressurized and Low-Pressure Feeders

i) Constant Cross Section Screws

These general purpose feeders can be used to convey and meter material to vessels at atmospheric pressure, to compression screws of pressurized feeders, or to rotary air locks isolating conversion process vessels. This type of feeder does not distribute input material entering the receiver. A single screw feeder is frequently used to supply fuel to boilers. These feeders can operate by on-off control, although proportional control can be applied for load-following capability.

Because of natural mixing in fluidized-bed combustors, a single screw feeder can feed above the bed, a region normally operated at slight negative pressures. For large diameter combustors, multiple feeders are needed to prevent non-uniform combustion. Overfire feeding is not usually used for multiple chamber combustors. For gasifiers a single screw feeder must be followed by a rotary valve, piston injector or compression plug screw feeder to provide a gas seal. The same configuration may be required for pyrolyzers.

ii) Choked Screw Feeders

The screw lock feeder of Rise Louise Co. has potential for feeding boilers, fluid-bed combustors, fixed- and fluid-bed gasifiers and pyrolyzers because it operates with a plug seal capable of operating against a 49.8 kPa differential pressure. Unfortunately, no experience has been obtained for wood chips, sawdust or hog fuel and the permeability of the wood plug to gas back-pressure is not known. A similar device is used by Rettew Associates Inc. to feed sawdust and sander dust to wood-fired furnaces and incinerators.

iii) Multiple Non-Intermeshing Screws

This design of multiple screw feeder has merit as a bridge-resistant surge-free feeder to distribute input material to a receiving vessel. It is useful for supplying bulk coal, wood, etc., from storage to a metering screw feeder, air locks, plug screw feeders or pistons injecting to pressure vessels.

iv) Concentric Double Screws

In this class of feeder the dual concentric screws are mechanically linked so that the larger outer screw conditions the solid input material and feeds it to the smaller inner metering screw which transfers it to the process. These units provide accurate metering to ± 1 to 2 percent. These devices are used where continuous, adjustable and accurate feed of solids to a conversion process are required. They can be followed by devices such as air locks, plug screws or pistons etc. for feeding pressurized vessels.

v) Single Screw Underfire Stoker

The screw feed underfire stoker is well known for feeding coal to domestic and industrial furnaces. Sorenson Energy Inc. and the Will-Burt Company have used them successfully to feed wood pellets as well as paper and straw pellets. A

Will-Burt Company customer has modified their underfired stoker for handling wood chips and hogged fuel, but details are not available. The Worley Equipment Company uses a progressive screw (pitch increasing in direction of flow) to prevent packing at the end of the screw and to reduce power up to about 50 percent. The Vynke design boiler uses a reverse flight at the end of the screw to force wood residues up into the fuel bed.

vi) Variable Section Screw With Metering Tube

This C.E. Bauer feeder is used widely in the pulp and paper industry to precondition pulp chips and to supply a rotary valve with a constant, metered flow of material for admission to a pressurized digester. Exhaust steam is used to drive out air from the feed and to preheat the material.

b) Pressure Feeders

i) Variable Cross Section Screw

A feeder developed by Sunds Defibrator Ltd. feeds a plug of wood chips through a hydraulically controlled choke. The feeder will feed into pressurized vessels at a differential pressure of up to 275 kPa. The plug screw provides a compression ratio of 1.7/1 v/v. The extended cone design provides a compression ratio of 2/1 v/v. Sunds do not have experience with hog fuel or bark, but feel bark could be handled if shredded to increase its density. Sanderdust could plug the 4.76 mm holes in the casing thereby preventing drainage of presswater. No extrudate breaker or distributor is provided. This feeder could have application for feeding a medium pressure fluid-bed combustor, fixed and fluid-bed gasifiers and pyrolyzers.

ii) Twin Counter-Rotating Intermeshing Screws

This design is marketed by the C.E. Bauer as the "Helipress". The twin screws operate inside a non-clogging wedge wire bar draining screen which encompasses 180 degrees of each screw. The counter rotating screws handle many difficult to handle feed materials for medium pressure de-watering or thickening of pulps and fibrous slurries in the pulp, paper board, fruit, grain and oil seed industries.

The twin screw is also used as a prefeeder to the high-pressure Bauer "Pressafiner". Each series of screw flights is spaced on the shaft to provide compression zones to maintain uniform dishcarge pressure as well as an intact plug. The counter-rotating screws are self cleaning.

The counter rotating action may cause some abrasion with dirty feed materials. This feeder could have application for medium-pressure fluid-bed combustors, as well as fixed- and fluid-bed gasifiers.

iii) Twin Co-Rotating Intermeshing Screws

This design is represented by the Werner and Pfleiderer Corp. feeder. This feeder has been used to continuously feed coal into high-pressure reactors at 427°C and 10,340 kPa. It can feed to a maximum pressure of 2,680 kPa. The screws are self wiping and can handle dry coal as well as moist material. It is modular in design so one can adjust the length/diameter ratio, replace barrels and liners and use different screw elements to allow adjustment of strength of seal. It handles abrasive coal well.

The manufacturer expects that bark and hog fuel to be less abrasive than coal which has been fed successfully. So far only wood sawdust has been fed, this being to a hydrolysis process. The screws are driven at a constant speed.

Metering is done by belt, rotary valve or screw feeders prior to the twin co-rotating compression screws. The feed must be prepared to be less than 3.8 cm. This unit should be applicable to high-pressure gasifiers.

iv) Single Screw Air Lock Feeder

This design is represented by the Fuller-Kinyon feeder. The screw rotates at relatively high speeds of 570 to 1,200 rpm to inject dry, pulverized free flowing materials into a pressurized pneumatic conveying system. The solids may be conveyed to a pressurized lock-hopper type of receiver from which it is injected to a conversion process. Alternatively the combustible solids could be injected with air directly into an atmospheric or pressurized combustor. Its most likely application would be to feed pulverized coal or wood to a pressurized receiver from which it would be metered by other feeders into a pressurized conversion system such as a fluid bed combustor, fixed or fluid bed gasifier or pyrolyzer. This concept of transfer has been tried in the T.V.A. Coal Feed Test Facility, but can not be considered proven technology.

v) Plug Screw Feeder

In this feeder, a compressed plug of coal or wood is produced downstream of the screw discharge to act as a seal against gas back-pressure from a pressurized conversion system. This design allows direct injection of fuel into the conversion reactors space. In some cases a hopper inside the pressurized vessel may be necessary to break up the compressed extruded product. Gard Inc. modified the Fuller-Kinyon Screw Pump to compress coal in a straight seal section. Proof-of-concept testing has been done on lump coal feeding into 414 kPa with good gas sealing. Near the maxiumum pressure there is a tendency for the coal plug to fluidize. The General Electric Company has installed a similar unit with an adjustable die in the seal on an operating gasifier. They have 7 hours completed of testing feeding coal plus tar into 2,068 kPa. Neither the Gard or General Electric units have been tried on wood residues.

Koppers Inc., Sprout Waldron Division, offer commercial equipment using a convergent/divergent cone to form a plug and to feed wood chips into pressurized digestors at 1,034 kPa. A back-pressure valve closes if the plug seal is lost.

These plug screw feeders should be applicable for feeding compressed wood to pressurized fluid-bed combustors, fixed- and fluid-bed gasifiers and pyrolyzers.

vi) Conical Feeder With De-Watering Cage

This design is represented by the "Pressafiner" of the C.E. Bauer Process Group. It is capable of forming a plug seal and applying pressures of up to 68,950 kPa on fibrous material such as wood chips.

The action de-waters and breaks up fibre bundles to provide surface for reaction. This feeder has not been used to feed wood conversion systems. For wood chip fuels, the unit is expected to funtion well.

vii) Constant Section Screw With Reciprocating Piston

This combustion is utilzed in a new design called a "Co-axial" feeder developed by Stake Technology Ltd. A relatively high-volume, low-pressure unit (153 mm screw, 254 mm ram) is operating successfully on a low-pressure wood gasifier in Hearst, Ontario. Dry wood powder, chips, sawdust and hogged trim from a plywood mill are being fed at about 4.5 t/h.

A lower-volume, high-pressure unit (139.7 mm screw, 203.2 mm ram) is being used to feed a steam pressurized wood hydrolysis unit to produce cattle feed. The manufacturer indicates that straw, bagasse, cotton gin, bark, sawdust and whole tree chips have been fed successfully.

The company indicates that the feeder can be modified to handle and de-water feed material having a moisture content up to 70% and a size up to 5 cm. They also indicate, however, that they have not yet commercialized this de-watering unit, although trial runs of a prototype have been completed (Stake Technology).

The rapid cyclic application of compressive force provided by the reciprocating ram enables the feeder to operate with a considerably reduced amount of power. The design also provides a short filtrate travel giving a high dry solids content in the product. A compressed plug of feed material provides an effective seal agianst back-pressure gases from the pressurized conversion reactor. There could be jamming problems with fibrous material such as cotton gin and course wood residues like hogged fuel. In the present design there is some feedrate constraint due to the inability of the de-watering zone to remove all of the expressed filtrate. This condition is being corrected.

This unique design should find application as a feeder to pressurized fluid-bed combustors, fixed- and fluid-bed gasifiers and pyrolyzers. The ability to feed into pressures of 2,400 to 5,500 kPa is anticipated.

viii) Constant Section Reciprocating Screw

This design, was developed by Ingersoll-Rand Research Inc. It has undergone about 200 hours of pilot plant testing on coal and is now installed on a gasifier for verification runs. If has been found that keeping the feeder cool results in the lower power consumption and best rate of feed. Therefore, the screw and liner at the discharge end is designed to be water-cooled. A continuous run of 9 hours has been made feeding dry coal against 2,412 kPa. Continuous runs have also been made feeding coal plus tar (binder-lubricant) into 5,170 kPa. Negligible back-pressure leakage occured under these conditions. In a static test, no leakage occured at 6,890 kpa back-pressure. It has been found that considerable wear can be tolerated without affecting performance as to power and output, all sizes of coal including fines can be fed satisfactorily. Wear of the screw and the barrel occurs mainly at the discharge end.

Wood residues have not been tried but the developers are interested in extending the application of this design which they feel could be a universal feeder.

Based on the data available, the feeder appears to have considerable potential for feeding wood residues. In any such application there is some potential for a buildup of material behind the screw unless sufficient opening is left for self-cleaning.

5. Status of Technology and Use

From the foregoing, it can be seen that several types of feeders are available for feeding wood residues to atmospheric or low-pressure conversion systems and to pressurized conversion systems operating up to about 10,340 kPa. The feeders that exist already, the designs that are promising and warrent futher investigation, and the potential problems of promising designs are discussed under the headings of non-pressurized and pressurized feeders.

a) Non-Pressure Feeders

Of the non-pressurized screw feeders, the constant cross section, multiple non-intermeshing, concentric double-screw, underfired stoker and variable section screw with metering tube are well known and widely used for feeding wood residue.

The choked screw design manufactured by Rise Louise Inc. and others is a promising design which warrents futher investigation. This type needs to be tested with various sizes of wood residues to determine the ability of the wood plug to seal against low gas back-presssures. This function is particularily important to contain toxic gases such as carbon monoxide generated in gasifiers.

The potential problems of the choked screw for residues are as follows:

- inability to seal against even low gas back-pressures because of the voids between pieces of wood particularly for larger sizes such as bark and hogged fuel;
- the inability of wood residues of the larger sizes such as bark and hogged fuel to flow past and around corners and past the choke;
- the possibility of jamming of the feed screw by bridged or oversize pieces of wood with the consequent stoppage of feed flow and possible failure of drive motors.

b) Pressure Feeders

There are eight classes of screw feeders that can be used to feed wood residues into pressurized conversion systems.

The variable cross section feeder represented by the Sunds Defibrator Ltd. design is well known in the pulp industry for feeding wood chips to steam pressurized digesters. It is a promising medium pressure high volume feeder that needs to be tested for feeding wood residues such as hogged fuel and verified for feeding bark. The potential problems envisioned are:

- -jamming of the compressed plug at the choke because of bridging of oversized wood particles;
- -plugging of the converging conical screw with stringy fibrous type bark such as derived from cedar etc.;
- -leakage of back-pressure gases because of the larger voids in coarse wood residues and a relatively short seal plug section.

The twin counter-rotating intermeshing screw feeder represented by the C.E. Bauer Group "Helipress" has been commercially available for some time and used as a medium-pressure prefeeder to supply wood pulp to the compression screws of high pressure de-watering presses. It has promise for handling difficult materials like bark and logged fuel because of the intermeshing design. The potential problems anticipated would be:

- -significant abrasion because of the counter-rotating action;
- -jamming of the screws by large pieces of wood and foreign materials between the intermeshing flights.

The twin co-rotating intermeshing screw feeder represented by the Werner and Pfleiderer Corp. design is commerically available for medium- to high-pressure applications. It shows promise because the design can move a plug of material held between the screws in a figure "8" path into high pressures with a minimum of abrasion. It needs to be tested with bark and hogged fuel to determine the vulnerability to jamming with oversized material. The potential problems envisioned are:

- -the inability of oversized input particles to enter the continuous plug space between the co-rotating screws;
- -jamming of odd sized pieces of wood and foreign materials between the screws;

-leakage of high pressure gas through the larger void potentially possible between compressed pieces of bark or hogged fuel;

-binding and sever wear of the co-rotating screws because of sand, etc. frequently present in bark and hogged fuel.

The single screw airlock feeder represented by the Fuller-Kinyon Screw Pump of the Gatx-Fuller Company is commerically available. It shows promise as a device for continuously feeding free flowing wood residues into medium-pressure pneumatic transfer systems at a relatively high rate. It needs to be tested for its ability to handle sized wood residues. The potential problems envisioned are:

-the inability to handle wood residues larger than fine sawdust;

-jamming of the high speed screw with potential damage to the screw and drive mechanism.

The Plug Screw Feeders are commercially available or have passed proof-of-concept tests for feeding high-pressure reactors. The commercial unit represented by Koppers Inc., Sprout- Waldron Division needs to be tested on several wood residues other than wood chips. The modified Fuller-Kinyon feeder developed by Gard Inc. and the feeder developed by General Electric Co. need to be tested with wood residues. The potential problems envisioned are:

-jamming of the compression feed screw with unsized oversized wood residues

-inability of the wood residue to seal against the same high back-pressures possible with coal

The conical feeder with de-watering cage is represented by the "Pressafiner" developed by the C.E. Bauer Process Engineering Group. It is primarily a de-watering device. It is commercially available for applying relatively high pressures to wood chips. Because it can continuously handle wood chips at very high pressures on a production basis, it shows promise as a wood residue feeder for high-pressure conversion systems. The potential problems envisionsed are:

-The need for a pressure prefeeder;

-the fluid drainage holes in the screw cage may not allow adequate gas sealing against gases at high pressure;

-a modification to the screw cage may be necessary to provide a high-pressure gas seal for use as a direct feeder to pressurized wood conversion systems.

The constant section screw with reciprocating piston is anovel combination of feeder components developed by Stake Technology Limited. The Co-Axial feeder shows promise for feeding wood residues because of the relatively low power comsumption requirement of this unique design. Further operation of the feeder with wood residues is needed to better define its limitations. The potential problems envisioned are:

-jamming of the feeder screw feeding the co-axial reciprocating piston;

-jamming of larger wood particles in the seal section following the reciprocating piston;

-the inability to seal against high pressures because os the high porosity of coarse wood residues.

The constant section reciprocating screw is a unique application of screw feeders developed by Ingersoll-Rand Research Inc. It shows promise as being a universal feeder and should be tested on wood residues such as sawdust, bark and hogged fuel to determine if indeed this design could be generally applicable as a high-pressure solids feeder. The potential problems envisioned are:

-difficulties of getting coarse wood residue particles into the compression screw to provide a tight plug;

-jamming of the rotating screw during the retracting cycle resulting in an inadequate plug seal and stoppage of the drive;

-the inability of a flapper type choke to provide a sufficiently compact seal to prevent back flow of gases from a high-pressure conversion system.

6. Manufacturers

The manufacturers of screw feeders surveyed in this study were:

Aco Sales & Engineering Ltd.
American Fyr-Feeder Engineers
Acrison Inc.
Argusfyr
B.F. Gump Div., Blow-Knox Food & Chemical Equip. Co.
Block-Clawson
C.E. Bauer
Carman Industries
Drawz Stoker Mfg. Co.
Gatx-Fuller Co. (Fuller-Kinyon Pump)
Gard Inc.
Feed Screws Div., New Castle Industries
Ingersoll-Rand
J & M Industrial Supply Ltd.
K-Tron Corp.
Koppers Co. Inc. (Sprout Waldron Div.)
Metal Fab Inc.
T.R. Miles Consulting Design Engineers
Miller Hofft Inc.
Moldrow Dust-Control Systems
Pennwatt of Canada Ltd.
Rise Louise Corp.
Sorenson Energy Inc.
Stake Technology
Sunds Defibrator Ltd.
Thomas & Muler Co.
Wennberg Systems Ltd.
Will-Burt Co.
Winona Attrition Mill Co.
Werner Pfleiderer Corp.
Wyssmont Co. Inc.
Worley Equipment Inc.

O. Vibrating Feeder

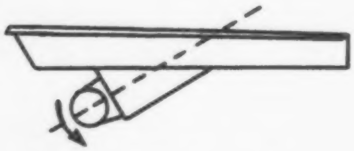
1. Design and Operating Principle

A vibrating feeder consists of a wide vibrating trough usually inclined downward. Vibratng feeders may be categorized by how the drive system transmits the vibratory action to the trough, this being either by "direct force" or "tuned drive" systems.

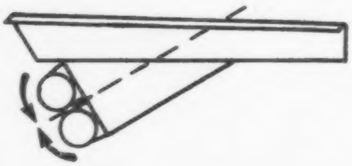
Direct force vibrating feeders are driven by mechanical rotary vibrating drives consisting of eccentric weights attached directly to the feeder trough (Figure VI-54). Thus, the driving force is transmitted directly from the mechanical drive to the feeder. A tuned drive system is basically a two mass, spring-connected system (Figure VI-55). With the proper selection of the spring constant, a relatively small existing force is amplified to generate a vibrating motion by taking advantage of natural magnification of vibrational amplitudes that occur when a vibrating system is operating near resonance. The driving force may be an electromagnet, or single or multiple eccentric weights.

To move material along the length of the trough, both types of vibrating feeders rely on the same principle. When the feeder is operating, the trough oscillates along a straight line. The resultant of the linear vibration of the trough on the particles is a repetitive series of throws and catches that moves them along the trough. Figure VI-56 shows this principle with the particle trajectory exaggerated for clarity. The particle is in contact with the trough from points A to B and is in free flight until it returns to the trough and the cycle is repeated. The linear velocity of the particle is thus dependent upon the frequency of vibration and the amplitude or stroke. Typically, this velocity ranges from 10 to 20 m/min for direct drive feeders and 0 to 20 m/min for tuned drive feeders.

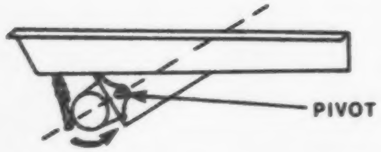
The direct force feeder is used generally to feed at a steady feed velocity, although some manufacturers supply variable speed motors. Otherwise feedrate is controlled by the feeder loading mechanism, or by mechanically changing the feeder slope. Tuned feeders using electromagnetic drives use simple voltage control to the magnet to give a complete range of feedrate control from zero to maximum. Those feeders using electromechanical drives control feedrate by similar means as the direct drive feeders.



A. SINGLE ROTARY

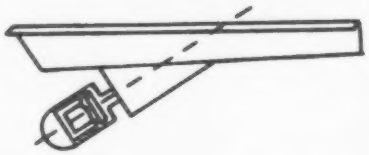


B. DUAL ROTARY

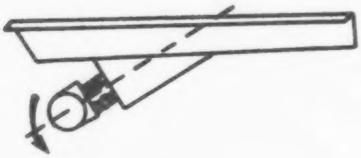


C. SINGLE ROTARY WITH PIVOT MOUNT

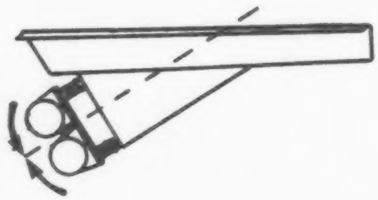
FIGURE VI-54 DIRECT FORCE VIBRATING FEEDER



A. ELECTROMAGNETIC



B. ELECTROMECHANICAL
SINGLE MOTOR



C. ELECTROMECHANICAL
DUAL MOTOR

FIGURE VI-55 TUNED DRIVE VIBRATING FEEDER

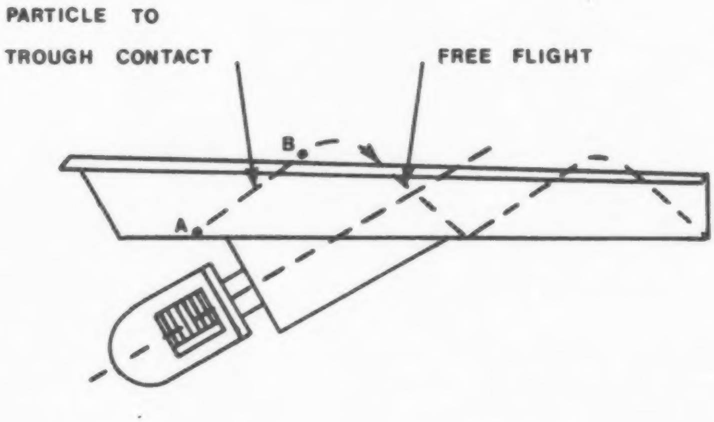

PARTICLE TO
TROUGH CONTACT
FREE FLIGHT
B
A

FIGURE VI-56 MOVEMENT OF A PARTICLE BY VIBRATION

2. Performance Characteristics and Costs

Vibrating feeders are used to convey material and require other mechanisms for metering and distributing functions. These feeders are most often used in conjunction with feeder chutes for direct feed to conventional conversion systems.

The capacity of a vibrating feeder is dependent upon trough width, bed depth, material density and linear velocity. Vibrating feeder capacities may be calculated using the relationship:

$$C = 0.06\ Wd\rho V$$

where: C = capacity (t/h)
W = trough width (m)
d = bed depth (m)
ρ = material density (kg/m^3)
V = feeder velocity (m/min)

For the case of wood residue, assuming the material density is 320 kg/m^3, the capacity equation becomes:

$$C = 19.2\ WdV \text{ (t/h)}$$

Power requirements can be estimated based on the area of the trough by using established multiplying factors. For direct drive feeders this factor is 1.5 times the cross-sectioned area (LW) in square meters:

$$P = 1.6\ LW;$$

and for tuned drive feeders this facor is 1.2:

$$P = 1.2\ LW.$$

Both types of feeders can adequately handle all non-sticky material up to 20 cm in size. A tuned drive vibrating feeder is usually better suited to handling fine powdery material and is less prone to material adhering to the pan than the direct drive feeder. Typical characteristics of both types of vibrating feeders are shown in Table VI-13.

Costs for vibrating feeders are dependent on type of service, capacity, type of drive and feeder length. Typically, vibrating feeders cost between $450 and $800 per tonne per hour capacity.

TABLE VI-13

Typical Characteristics of Vibrating Feeders

PARAMETER	DIRECT DRIVE	TUNED DRIVE
Width (m)	0.6 - 2	0.6 - 2.7
Length (m)	1.5 - 6.1	1.5 - 4.3
Capacity (t/h)	25 - 550	0 - 1,000
Conveying Velocity (m/min)	10 - 20	0 - 20
Power Requirement (kW)	2 - 20	1.5 - 5
Applications - good	5 cm - 20 cm	up to 20 cm
- fair	minus 5 cm	

3. Applications and Guidelines for Proper Use

Vibrating feeders are suitable for conventional non-pressurized wood conversion units and must be used in conjunction with feeder chutes or some other feeding mechanism. Vibrating feeders do not have the ability to seal and cannot be directly used with pressurized conversion systems. Systems requiring good feedrate control and high turndown ratios should use the tuned drive type vibrating feeder.

Generally, wet or sticky material should not be fed with vibrating feeders. However, in some cases, tuned drive vibrating feeders may handle such material since they operate at a high frequency which aids in keeping the pan clean. Direct drive feeders which operate at much lower frequencies (900 to 1,800 cycles per minite versus 3,600 cycles per minute for tuned drive feeders) should not be used for feeding sticky material.

Vibrating feeders can virtually handle all sizes of material (Table VI-14), however, problems may be encountered with finer particles due primarily to two reasons. First, if the material is very fine and dry, problems of dusting may arise, although this may be easily alleviated with dust covers. Secondly, fine material will have significant interparticle forces which prevent the particles from separating when they are thrown from the trough bed. Consequently, air cannot pass through them and a partial vacuum is formed, resulting in drastic reduction of the feedrate.

4. Status of Technology and Use

The utilization of vibrating feeders offers several advantages over other types of feeders. They have high capacity potential, yet are of simple construction, have few moving parts and low unit power consumption. As a result capital, installation and operating costs on a per unit capacity basis are relatively low. In addition, vibrating feeders may handle a wide range of material sizes and spillage is minimal. Tuned drive feeders also offer the advantage of having excellent control of the feedrate and uniform flow of material.

The greatest disadvantage of vibrating feeders is that their feed extraction is not positive and, therefore, they do not have metering capabilities. In addition, they must be used with feed chutes to feed conversion systems and may encounter problems with feeding sticky or very fine material.

TABLE VI-14

Suitability of Vibrating Feeders for Feeding Various Sizes of Material

SIZE	DIRECT DRIVE	TUNED DRIVE
Minus 20 cm (coarse)	Good	Good
Minus 5 cm (medium)	Good	Good
Minus 1 cm (fine)	Fair	Good
Minus 100 mesh (very fine)	Fair	Good
Minus 200 mesh (powder)	Fair	Fair

5. Manufacturers

Manufacturers which supply vibrating feeders include the following:

Armstrong Jones Ltd.
Barber Green Company
Eriez of Canada Ltd.
Feeder Corporation of America
FMC Corp.
Iowa Manufacturing Company
Jeffrey Manufacturing
  Division of Dresser Industries Ltd.
National Air Vibrating Company
Rexnord
Syn-Energy
Vibranetics
Webster Mfg Co.

VII. FINDINGS

A. Non-Pressure Feeders

Feeders for conversion systems operated at near zero differential pressure are simply conveyors, and ample equipment exists for satisfactory handling of wood fuels of all types and sizes. No new feeders were identified in the survey which were an improvement over existing feeders for non-pressure applications.

Guidelines for proper use of non-pressure feeders are given in Chapter VI.

B. Low- and Medium-Pressure Feeders

The upper limit of differential pressure for these feeders was based on the limits set by manufacturers, resulting in a value of about 1,000 kPa. The distinction of this group of feeders as different from high-pressure feeders is relatively arbitrary since this latter group could be used for the same duty.

The wood feeders falling within this group were developed for feeding into steam-pressurized reactors (digestors) usually held at pressures below 1,000 kPa, although steam-explosion processes use pressures up to about 2,400 kPa.

Rotary and screw feeders are available that have been well proven for feeding wood chips and sawdust. The most common problems with the rotary feeders are jamming with oversize material, leakage of gases and a need to vent gas contained in returning valve pockets. Screw feeders suffer from jamming with oversize and stringy materials. These feeders do not require venting of process gases and, with blow-back protection, leakage is not a problem.

Lock hopper feeders can also be used for feeding into low- and medium-pressure reactors. These feeders have been operated successfully with wood residues, but may have problems with poor solids discharge and venting of substantial amounts of process gases. The control system for lock hoppers has to be more sophisticated than most other feeders due to cycling of valve positions and lock hopper pressures that are required.

Some new piston and screw feeder designs have been developed for high-pressure applications that could be readily adapted to low- and medium-pressure applications.

C. High-Pressure Feeders

The feeders identified as being capable of feeding materials against differential pressures in excess of 1,000 kPa are given in Table VII-1. Based on the data compiled in this study, the feeders were assessed as to their ability to feed wood residues having one of three particle size ranges typical of common residues. The suggested feeds for the feeders and an indication of whether feeding of the residues has been proven, demonstrated or needs further testing are indicated in Table VII-1. Feeders for which a size range is left blank are believed to be poorly suited to such particle sizes and other feeders are probably more suitable. The above classification is only a preliminary guide because of the lack of conclusive data.

One feeder of particular interest for coarse residues is the Ingersoll-Rand reciprocating screw feeder. This design has the attractive feature of allowing the drive screw to recede from the area of highest solids compaction. The plug of material can be allowed to build up to a length sufficient to seal the process unit so that the importance of the imposed compaction pressure is of less importance than for conventional fixed screw feeders which discharge against some type of flow constriction. The design uses the positive features of both piston and screw feeders.

TABLE VII-1

Potential High-Pressure Feeders for Wood Residues

FEEDER	OPERATED WITH WOOD RESIDUES?	SUGGESTED PARTICLE SIZES* FOR WOOD FEED		
		<1 cm	1 - 5 cm	>5 cm
C.E. Bauer Pressafiner	Yes	P	P	T
General Electric Srew Feeder	No	T	T	T
Ingersoll-Rand Piston Feeder	No	T	T	
Ingersoll-Rand Screw Feeder	No	T	T	T
Koppers Screw Feeder	Yes	P	P	T
Linear Pocket Feeder	No	T	T	
Lock Hopper Feeders	Yes	P	P	P
Lurgi Piston Feeders	Yes	T	T	
Rotary Feeders	Yes	P		
Stake Technology Screw Feeder	Yes	P	P	T
Werner Pfleiderer Screw Feeder	Yes	D	T	

*Based on general characteristics of the feeder design and data obtained in this study.

Key: P - Proven
D - Demonstrated
T - Needs Testing

REFERENCES

Conveyor Equipment Manufacturers, 1000 Vermont Avenue, N.W. Washington, D.C., 20005, "Screw Conveyors", CEMA Book 350, Second Edition (1980).

Field, S.F., Gard, Inc., "Continuous High Pressure Lump Coal Feeder Design Study", Proc. of Conference on Coal Feeding Systems, Jet Propulsion Laboratory, University of California, Pasadena, June 1977.

Stake Technology Ltd., "Design, Construction and Testing of a Bark D-Watering Device", Canadian Forestry Service ENFOR Project No. C-6.

APPENDIX I - LIST OF COMPANIES

COMPANY	FEEDER TYPE
Aco Sales and Engineering Ltd. 90 Harbour Avenue North Vancouver, B.C. V7J 2E1 (604) 988-1166	Pneumatic Rotary Screw
Acrison Inc. 20-T Empire Blvd. Moonachie, NJ 07074 (201) 440-8300	Screw
Aerolock Premier Pneumatics, Inc. 606 North Street Salina, Kansas 67401 (913) 825-1611	Rotary
American Coal Burner and Wood Stoker Corp. 1265 Rand Road Des Plaines, Illinois	Screw Fixed Grate
Armstrong Jones Ltd. 83 Sunrise Avenue Toronto, Ontario M4A 1B1 (416) 751-2380	Screw Vibrating
B.F. Gump Div. Blaw Knox Food & Chemicals Box 1041 Buffalo, NY 15240 (716) 895-2100	Rotary Screw
Barber-Greene Co. 400 North Highland Avenue Aurora, Illinois	Apron Vibrating
Beaumont Feeders Inc. 3900 River Road P.O. Box 599 Pennsauken, NJ 08110	Rotary

COMPANY	FEEDER TYPE
C.E. Bauer 1673 West 7th Avenue Vancouver, B.C. V6J 1S4 (604) 736-7704	Gate Rotary Screw
Beloit-Jones Dalton Ma 01226 (413) 443-5621	Rotary
BIF, A Division of General Signal Ltd. 25 Shaft Road Rexdale, Ontario M9W 4M3 (416) 247-6123	Belt
CEA Simon-Day P.O. Box 488 Winnipeg, Manitoba R3C 2J6 (204) 786-5781	Ram Rotary
Cantab Industries Ltd. Box 54 Toronto, Ontario M4T 2L7 (416) 923-2288	Pneumatic
Cassier Eng. Sales Ltd. 11 Progress Avenue Scarborough, Ontario M1P 4S7 (416) 298-1628	Screw Vibrating
Clarke's Sheet Metal Inc. 660 Conger Street Eugine, Oregon 44113 (216) 241-7157	Rotary
Combustion Service & Equipment Co. 20116 Babcock Boulevard Pittsburgh, Pennsilvania 15209 (412) 821-8900	Ram

COMPANY	FEEDER TYPE
Conspray Construction System 111 West Dyer Road, Unit B Santa Anna, California 92707 (714) 540-1274	Ram
Construction Machinery Co. Ltd. P.O. Box 231 Waterloo, Ontario N2J 3Z9 (519) 742-7151	Rotary
Dayton Automatic Stoker Co. P.O. Box 255 Dayton, Ohio 45404	Ram
Detroit Stoker Company 1510 - T First Street Monroe, MI 48161 (313) 241-9500	Ram
Drawz Stoker Mfg. Co. Rte 3 Minot, ND (701) 838-0643	Screw
Ducom Fluid Transfer 11535 First Avenue King of Prussia, PA 19406	Lock Hopper
Econo-Therm Energy Systems Corp. 11535 A K-Tell Drive Minnetonka, MN 55343 (613) 938-3100	Ram
Energy Div. of Zurn Industries 1422 East Avenue Erie, PA 16503	Traveling Grate
Eriez of Canada Ltd. 133 Oakdale Road Downsview, Ontario M3N 1W2 (416) 742-9993	Vibrating

COMPANY	FEEDER TYPE
Feed Screws Div. New Castle Industries 1398 Countryline Road New Castle, PA 16101 (412) 658-5601	Screw
Feeder Corporation of America 4429-T James Place Melrose Park, Illinois 60160 (312) 343-4900	Vibrating
Franklin Miller Inc. 235 Watchung Avenue West Orange, NJ 07052 (201) 736-3900	Rotary
Gatx-Fuller Ltd. 721 Progress Avenue Scarborough, Ontario M1H 2W7 (416) 438-6540	Rotary Pneumatic Screw Lock Hopper
General Resources Corp. 201 Third Street South Hopkins, MN 55343 (612) 933-7474	Rotary Pneumatic
Hydraulics Unlimited Mfg. Co. 601 Oak Box 207-T Eaton, CO 80615	Screws
IFE Systems Inc. 140-B KinderKamack Road Park Ridge, NJ 07656 (201) 529-5990	Feed Chute
Illinois Stoker Co. 102 West 7th Alton, IL (618) 465-7724	Traveling Grate
Industrial Furnace Co. 2711 Fifth Avenue South Birmingham, AL	Rotary Table

COMPANY	FEEDER TYPE
Ingersoll-Rand Box 301 Princeton, NJ 08540 (609) 921-9103	Ram Rotary Screw
Iowa Manufacturing Co. 916 16th Street N.E. Cedar Rapids, Iowa (319) 363-3511	Apron Belt
J & M Industrial Supply Ltd. 2899 Steeles Avenue West Unit No. 4 Downsview, Ontario M3J 3A1 (416) 665-2300	Belt Screw
James Eagen Sons Co. 204 West 8th Street Wyoming, PA 18644	Screws
Jeffrey Manufacturing Div. Dresser Industries Inc. P.O. Box 3080-T Greenville, SC (803) 288-7324	Vibrating
Kamyr Inc. Glens Falls, NY 12801 (518) 793-5111	Rotary Screw
Koppers Engineered Products Ltd. Sprout Waldron Div. P.O. Box 515 Waterloo, Ontario N2J 4A9 (519) 579-4210	Rotary Screw
K-Tron 20 Wanich Avenue Glassboro, NJ 08028 (609) 881-6500	Screw

COMPANY	FEEDER TYPE
Laclede Stoker Co. 4438 Hunt Avenue St. Louis, MO (314) 579-4210	Traveling Grate
Lamb-Cargate Industries Ltd. 1135 Queens Avenue New Westminster, B.C. V3L 4Y7 (604) 521-8821	Belt Ram
Macawber Engineering Inc. Clydesdale Street Blount County Industrial Park Maryville, TN 37801 (615) 984-5286	Pneumatic Lock Hopper
Merrick Seale Mfg. Co. 5350 Imperial Street Burnaby, B.C. V5J 1E6 (604) 430-1531	Belt
Metal Fab Inc. 140 Woodland Avenue Rochelle Park, NJ 0762 (201) 845-6060	Screw Feeder
Thomas R. Miles 5475 S.W. Arrowwood Lane Portland, Oregon 97225 (503) 292-2919	Lock Hopper
Miller Hofft Inc. 2415 W. Thompson Road Indianapolis, IN (317) 787-9385	Screw
Milltronics Ltd. 730 The Kingsway Peterborough, Ontario K9J 6W6 (705) 745-2431	Belt

COMPANY	FEEDER TYPE
Moldow Dust Control Systems Ltd. 5266 General Road, Unit 4 Mississauga, Ontario L4W 1Z7 (416) 624-6242	Pneumatic Rotary Screw
Morse Boulger, Inc. 53-09 97th Place Corona, NY (212) 699-5000	Ram Screw
Mount Jewett Foundry and Machine Co. P.O. Box 99 Bellwood, PA (814) 742-8421	Traveling Grate
National Air Vibrator Co. 6880 Wynnwood Lane Houston, Texas 77008	Pneumatic Vibrating
Pennwatt 925 Warden Avenue Scarborough, Ontario M1L 4C5	Belt Screw
Petrocarb Inc. 200-T Broadacres Drive Bloomfield, NJ (201) 893-0200	Pneumatic Lock Hopper
Prater Industries Inc. 1515 South 55th Court Chicago, Illinois 60650 (312) 656-8500	Rotary
Pulva Corp. 552 High Street P.O. Box 646-T Perth Amboy, NJ 08862 (201) 826-3450	Rotary
Rader Canada Ltd./Pacific Division P.O. Box 65567, Station F Vancouver, B.C. V5N 5K5 (604) 299-0241	Pneumatic Rotary

COMPANY	FEEDER TYPE
Rettew Associates Inc. Box 65 R.R. #1 New Manstown, PA 17073 (215) 589-2511	Screw
Renold Inc. Bourne Street Westfield, NY 14787 (716) 326-3121	Vibrating Belt
Rexnord Canada Ltd. 1181 Shippard Avenue East Willowdale, Ontario M2K 1C6 (416) 221-9361	Vibrating
Riley Stoker Corp P.O. Box 547 Worcester, MA 01613 (617) 852-7100	Pneumatic Lock Hopper Traveling Grate
Rise-Louise Corporation 16-T Passaic Avenue Fairfeld, NJ (201) 227-6727	Rotary Plow Screw Flight
Royal Institute of Technology Stockholm Sweden	Ram Lock Hopper
Semco Pneumatic Systems Ltd. 6999 Ordan Drive Mississauga, Ontario L5T 1K6 (416) 678-9301	Rotary
Sorenson Energy Inc. 1610 Industrial Road Salt Lake, Utah 84104 (801) 973-4700	Screw
Stake Technology 220 Wyecroft Road Oakville, Ontario L6K 3V1 (416) 842-4560	Screw

COMPANY	FEEDER TYPE
Sunds Defibrator Ltd. West Mall Business Centre P.O. Box 758 Brantford, Ontario N3T 5R7 (519) 759-1442	Screw
SYN-Energy Inc. Route 286 S. Indiana, PA 15701 (412) 349-7867	Vibrating
Thayer Scale, Wyer Industries Inc. 2 Thayer Park Pembrooke, MA (617) 826-8101	Belt
Thomas & Muller Co. P.O. Box 1930 Camden, NV 08101 (609) 963-3500	Screw
Union Heating Inc. 724 Walnut P.O. Box 308 Edmonds, Washington 98020 (206) 775-4588	Feed Chute
Vibranetics 5350 Imperial Street Burnaby, B.C. V5J 1E6 (604) 430-1531	Vibrating
Webster Manufacturing Co. 1100 West Davis Street Tiffin, Ohio (419) 447-8232	Vibrating
Wennberg Systems Ltd. 1468 Main Street North Vancouver, B.C. V7J 1C8 (604) 985-9141	Screw

COMPANY	FEEDER TYPE
Werner & Pfleiderer Corp. Machinenfabrik Theodorstrasse 10 Postfach 301220 7000 Stuttgart 30 West Germany	Screw
Will-Burt Co. 169-T South Main Street Orrville, OH	Screw
William W. Meyer & Sons, Inc. 8261 Elmwood Avenue Skobie, Illinois 60077 (312) 463-5127	Rotary
Winona Attrition Mill Co. West 5th Street Winona, MN (507) 452-2716	Screw
Worley Equipment Inc. 2301-T N. Knox Avenue Chicago, Illinois 60639 (312) 252-2830	Screw
Wyssmont Co. Inc. 1470 Bergen Boulevard Fort Lee, MD 07024 (201) 947-4600	Screws